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Erosional Processes on Forest Roads and Flow Duration Characteristics of the Horse Creek Streams

Larry C. Tennyson
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Bruce Prud'homme

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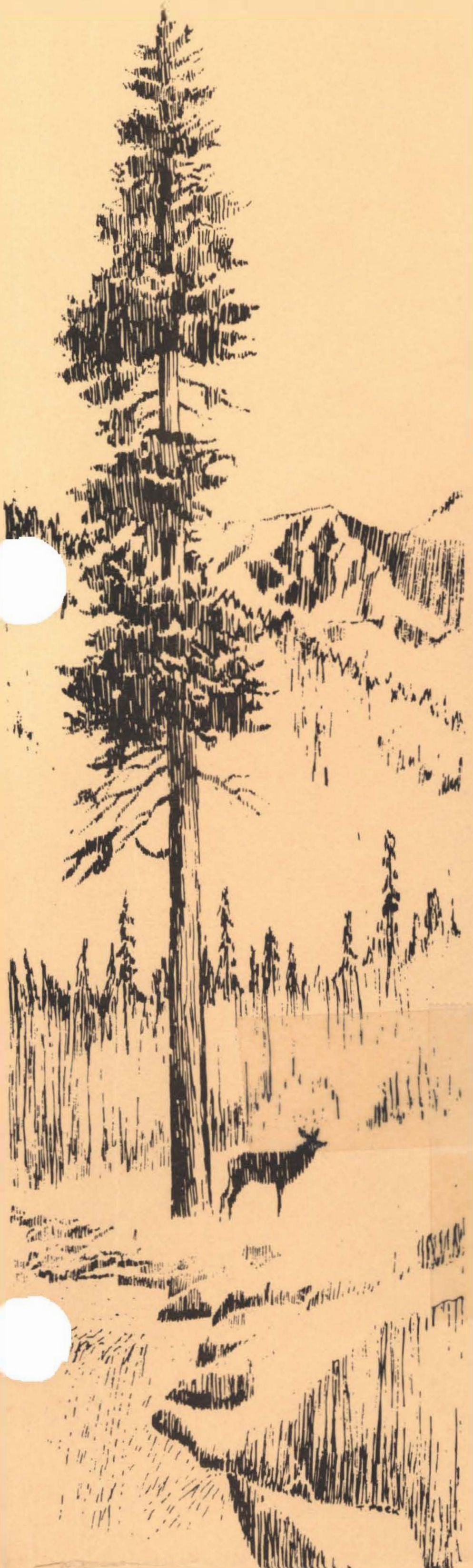

College of Forestry, Wildlife and Range Sciences

Forest, Wildlife and Range Experiment Station

University of Idaho

Cooperative Research Agreement INT-80-117-CA with USDA, Forest Service, Intermountain Forest and Range Experiment Station and College of Forestry, Wildlife and Range Sciences, University of Idaho

Completion Report Review Draft

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CHAPTER 1

INTRODUCTION

Present concern for the potential impacts land use activities can have on the water resource has prompted an increased interest in evaluating the effects of forest management practices on water yield and quality. The most widespread water quality problem associated with forest management and in particular silviculture and related road construction activities is accelerated site erosion with subsequent increased sedimentation of freshwater streams and lakes.

Logging roads are considered by many to be the major producers of instream sediments. Cut and fill slopes, road surfaces and the ditch systems are readily exposed to weathering plus wind and water erosional processes, thus, providing the major sources for sediment production on management areas. The President's Advisory Panel on Timber and the Environment (1973) reported that 95% of the erosion from timber harvesting operations results from associated road construction and maintenance.

The establishment of a road network on a watershed can also produce changes in streamflow. The increased areas of impermeability and concentrated surface flows associated with roads, can significantly affect local streamflow quantity and regimen. Peak streamflows are often higher and occur more readily after road construction compared to pre-road behavior. The degree and duration of high and low flows can also be affected by the presence of roads. The direct and indirect impacts of increased channel sediments and changes in streamflow patterns on water quality and quantity are many, varied and well documented. However, discussion of this subject is not within the scope of this text.

In 1965 the Horse Creek Administrative Research Project was initiated by the U.S. Forest Service. Horse Creek was selected as the particular area within the Meadow Creek Barometer Watershed in which "... to develop the methodology and resolve the problems of integrating intensive sedimentation control and stream channel protection measures into a practical and feasible timber sale and road development plan" (U.S.F.S. Meadow Creek Summary, 1973). The primary objective of the Horse Creek study is to evaluate the effects of a specifically designed timber harvest on soil and water, with a secondary objective to evaluate alternative road construction, stabilization, and maintenance on these same resources.

Road construction in Horse Creek began the summer of 1978 and was completed in the summer of 1979. Collection of data on road-related hydrology and erosion was initiated as soon as possible after construction was completed on each road segment and has continued to present.

The objectives of this study were to use data available from the Horse Creek Studies for the purpose of quantitatively and qualitatively describing erosion processes occurring on various road prism features and to evaluate flow characteristics of selected streams which may be impacted by the construction and existence of roads.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA

The Horse Creek Administrative Research Project is a study of paired watersheds; the East Fork and the Main Fork of Horse Creek. The East Fork drains approximately 3560 acres and the Main Fork about 4170 acres. These watersheds range in elevation from 6000 feet at the southern divide of the East Fork watershed to 4100 feet at the confluence. The mean elevation and median side slope of the East Fork watershed are approximately 5190 feet and 36 percent, respectively. The mean elevation and median side slope of the Main Fork watershed are approximately 4990 feet and 31 percent, respectively.

These watersheds border the Idaho Batholith. The rocks of this border zone are part of the Belt Super Group and are classified as sedimentary and metasedimentary. These rocks consist primarily of gnessic material which contains large proportions of quartz, plagioclase, muscovite, and biotite. The soils are moderately deep, well drained, loam to sandy loam with surface layers containing much loessial silt; and are classified as moderately shallow, well drained loams to sandy loams.

Weather at Horse Creek is influenced primarily by onshore Pacific air masses. For the 15 years of Forest Service record, average annual precipitation is 45 inches, with 60 to 70 percent occurring as snowfall. The average annual temperature is 37° Fahrenheit. The wettest and coldest month is January, with the driest and warmest month being August. Peak runoff which is produced by snowmelt, usually occurs in May or June, with low flows normally occurring by late August. The drainages are almost completely forested with vegetation dominated by old Grand Fir (Abies grandis) and its associated species.

Ten south facing subwatersheds are presently being gaged. These watersheds range in size from 56 to 360 acres, with mean elevations ranging from 4850 to 5400 feet. Average annual runoff from the ten subwatersheds for water years 1975-1979 ranged from approximately 12.7 area-inches to 29.8 area-inches. The ten gaged subwatersheds with their respective areas in acres, mean elevations in feet, and 5-year average annual runoffs are listed in Table 1.

Six of the ten designated subwatersheds have had road contruction. Nine of these will undergo some logging prescription in the summer of 1981. In addition, subdrainages 11 and 15 are roaded and will receive logging treatment. Subwatershed six will be used as a control with no roads or logging.

Construction of the first 7,905 feet of Road 9704 (Figure 1) was completed by August, 1978, the next 5,032 feet were completed by August, 1979, and the last 10,933 feet were completed by October, 1979. All of Road 9708 (7,193 feet) and Road 9709 (6,448 feet), except for the surfacing of 9709, was completed by late September, 1978.

Two different road design standards, with variances, were used on the Horse Creek Roads. Standard 1 is the current standard practice with the design objective of providing for smooth traffic flow at a constant 15 miles per hour. Horizontal and vertical alignment considers sight distance and grade breaks for relief of traffic flow, but not for relief of cut and fill height. The minimum curve radius (R) was 110 feet and curve widening was 400/R. The subgrade, travelway, and ditch widths were 16, 12, and 3 feet, respectively.

The objective of the standard 2 roads was to minimize cut and fill heights and to fit the terrain in an attempt to reduce road-related erosion

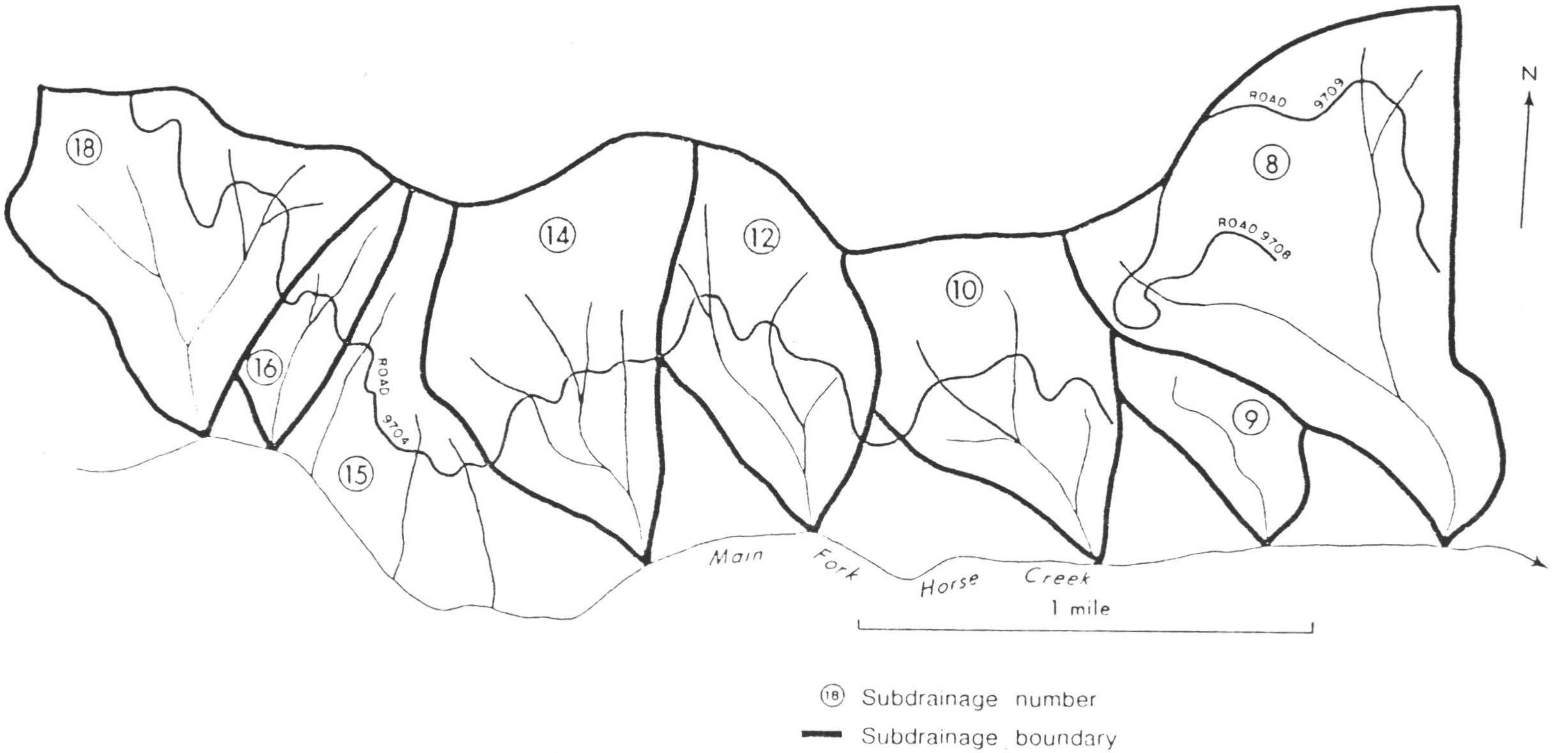

N
18
16
15
14
12
10
8
9
ROAD 9709
ROAD 9708
ROAD 9704
Main Fork Horse Creek
1 mile
⑱ Subdrainage number
Subdrainage boundary

Figure 1. A map of the roaded Horse Creek subdrainages illustrating the location of roads.

Table 1. Characteristics of ten gaged subwatersheds in the Main Fork, Horse Creek Drainage.

Watershed	Area (acres)	Mean Elevation (feet)	Average Annual Runoff 1975 - 1979	
			cfs-days	Area-inches
202	144	5000	77	12.7
204	352	5000	245	16.5
206	256	5000	212	19.7
208	360	5000	310	20.5
209	58	4850	44	18.0
210	167	5000	132	18.7
212	203	5200	179	21.0
214	159	5260	139	20.8
216	70	5380	55	17.0
218	204	5400	256	29.8

and drainage problems. The minimum curve radius (R) was 50 feet and curve widening was 200/R. Horizontal alignment provided for rolled grades for drainage relief and cut and fill slope heights were minimized. Subgrade, travelway, and ditch widths were 15, 12, and 1 feet, respectively.

Vertical height classes for cut and fill slopes in both design standards are as follows: Class 1 (0 to 10 feet), Class 2 (10 to 20 feet), Class 3 (20 to 30 feet), and Class 4 greater than 30 feet. Cut slopes were slightly steeper on standard 2 roads than on standard 1, and fill slopes had the same slope ratio ($1\frac{1}{2}$:1) on both standards.

Three road surfaces were used in Horse Creek. These surfaces included eight inches of rock with oil on the first 7,905 feet of Road 9704; asphalt on the next 5,032 feet of Road 9704; and native material with oil on the rest of 9704 and all of Roads 9708 and 9709.

Four different stabilization treatments were used on the cut and fill slopes. These included treatment 1 (hydroseed with mulch); treatment 2 (hydroseed with a straw/asphalt tack); treatment 3 (hydroseed only); and treatment 4 (no treatment).

A summary of some of the important Horse Creek road characteristics that may influence surface erosion of the fill slopes is presented in Table 2. The plan area disturbance of the fills ranged from 0.0029 to 0.0058 mi^2/mi. Also listed in the table are fill slope treatment, road surface, road standard, and percent of road length in each height category. Table 3 provides similar information for cut slopes. Plan area disturbance of the cuts ranged from 0.0012 to 0.0034 mi^2/mi.

Table 2. Road and fill slope characteristics for the Horse Creek roads.

Road	Station	Fill slope disturbance mi^2/mi[1]	Fill slope Treatment[2]	Road Surface[3]	Road Standard	Percentage of road length in each height category[4]				
						1	2	3	4	5
9704	0+00-79+05	0.0029	H	G	I	61.0	31.4	6.6	1.0	0.0
9704	79+05-129+37	0.0032	S/A	A	II	44.8	29.0	9.2	5.7	11.3
9704	129+37-194+00	0.0044	None	N	I	16.8	17.3	19.2	9.9	36.7
9704	194+00-238+70	0.0059	S	N	II	17.1	33.5	30.0	17.7	17.2
9708	0+00-73+15	0.0031	S/A	G	II	44.7	34.0	10.7	1.8	8.8
9709	0+00-64+48	0.0036	S/A	G	II	41.8	21.1	13.2	6.1	10.8

[1] Horizontal area of fill slopes per mile of road, excluding sections of road with no fill slopes.

[2] H=hydromulch plus seed, S/A=straw mulch with an asphalt tack plus seed, S=seed (no mulch).

[3] G=gravel, A=asphalt, N=native soil.

[4] Categories 1, 2, 3, 4, and 5 are respectively 0-10, 10-20, 20-30, greater than 30 vertical feet, and no fill slopes.

Table 3. Road and cut slope characteristics for the Horse Creek roads.

		Cut slope[1] disturbance	Cut slope[2]	Road	Trap installation	Cut slope height category				
						1	2	3	4	5[3]
9704	0+00-79+05	0.0017	H	I	09-14-78	47.0	46.7	0.7	0.0	5.6
9704	79+05-129+37	0.0017	S/A	II	08-28-79	32.7	46.0	7.7	0.0	13.6
9704	129+37-185+10	0.0034	None	I	10-03-79	13.8	25.2	48.3	12.7	7.0
9704	185+10-238+70	0.0015	None	II	10-03-79	42.3	19.7	10.7	2.9	24.3
9708	0+00-73+15	0.0012	S/A	II	09-27-78	50.4	39.1	4.9	0.0	5.6
9709	0+00-64+48	0.0016	S/A	II	09-28-78	43.6	26.4	14.7	2.2	13.1

[1] These values are based only on that length of road with cut slopes.

[2] H=seeded plus hydromulch, S/A=seeded plus a straw mulch with an asphalt tack.

[3] Category 5 is that portion of the road with no cut slopes, i.e., through fill sections.

CHAPTER 3

FILL SLOPE EROSION

INTRODUCTION

The detachment and transport of sediments from road fill slopes is considered one of the primary sources of sediments to natural flowing streams; particularly at locations where the road crosses these streams. Many factors can affect the degree of erosion on fill slopes during the life span of a road. The factors evaluated in this study were; time since construction, winter and summer seasons, height of slope, type of slope surface protection after construction, windrowing of slash at the toe of the slope and type of road surfacing.

METHODS

Fill slope erosion was measured by use of four-foot long galvanized sheet metal troughs with wood bracing. The troughs were placed with the upper edge flush with the ground and immediately below the toe of the fill slope. Duff and litter were removed from the surface of the selected site and the ground surface was leveled. Troughs were then installed and anchored with wooden pegs.

Troughs were placed so that each of the four vertical slope height classes were sampled for fill slope erosion. The first trough in each height class was located at random with the remaining spaced at fixed distances. Sampling intensity was limited to approximately one percent of the surface area to minimize interference of natural debris movement to streams.

Installation of troughs was accomplished as soon as possible after completion of road construction. Sampling began after the first rainfall event and continued periodically through the summer after major rainfall events (> 0.3 inches). Final sampling of the first summer season was conducted before troughs became snow covered. Sampling commenced again with the disappearance of snow cover in the spring and continued as described until snow cover the following fall. The first erosion measurement following the disappearance of snow cover in the spring is hereafter referred to as winter erosion. The sum of subsequent measurements until snow cover is designated as summer erosion. Volumes of fill slope erosion were determined by volumetric measurement techniques. Erosion, as used in the context of this report, is the amount of displaced soil being transported beyond the toe of the slope.

Both surface erosion and mass wasting have been observed on fill slopes of the Horse Creek roads. Surface erosion occurs primarily as sheet and rill erosion during and immediately after major rainfall events with rain being the primary driving force. This is particularly true in the first few summer months following construction. Fredricksen (1965) found similar results. He noted that runoff from the first few rainstorms following road construction on a study watershed carried 250 times more sediment compared to an adjacent undisturbed watershed. Mass wasting occurs when small slumps of material dislodge from the slope and move down gradient as earthflows. This phenomenon occurs most frequently in the spring when the slopes are saturated from snowmelt.

Intuitive analysis of the temporal, spatial and physical parameters which affect erosional processes on fill slopes provided the basis for the following statistical analysis. Tests for statistical differences in the degree of erosion on fill slopes were made using the two tailed Student's t-test for means with unequal variances, unpaired observations, and $\alpha = 0.10$.

Statistical tables which included number of observations, means, and variances for each unique road section were developed prior to application of the Student's t-test (Appendix 1). The following erosion comparisons were made: summer versus winter, first summer versus succeeding summers, first winter versus succeeding winters, differences between height classes, and windrow protected troughs versus troughs without windrow protection. In some cases, tests were made for different combinations of possible influencing factors from road surfaces and slope treatments. Since fill slopes did not differ in design from standard 1 to standard 2, no tests were made between standards on fill slopes.

When comparing first and subsequent summers or first summer and winter erosion, a common unit of comparison was needed. In those cases, erosion unitized with precipitation was used for testing. This unit change was calculated by dividing the amount of erosion for the period by the amount of precipitation which occurred during the period. The resulting adjusted units were ft^3/trough/inch of precipitation. Consequently, the statistical tables (Appendix 1) have information for cumulative erosion as well as adjusted and nonadjusted seasonal erosion.

Roads 9708 and 9709 were not completely finished during the first summer of construction, therefore, all exposed surfaces on 9709 and the cuts and fills on 9708 (road surface was completed) were sprayed with a straw/asphalt tack until the next construction season. Also, many troughs were destroyed in subsequent road work on 9709. Consequently, data for these roads were not as complete as 9704 data at the time this analysis was conducted. Therefore, analysis were limited to road 9704 fill slope data.

RESULTS AND DISCUSSION

Obvious differences in trends in erosion data did not in most cases prove statistical significance. The existing high variability about the means, and small sample sizes contributed to a lack of significance in a majority of the tests.

Analysis of differences between summer and winter erosion on fill slopes suggested a definitive trend of comparatively higher erosion during the summer months (Figure 2). Average first summer erosion on the fill slopes below the asphalt surface section, treatment 2, height class 2 (station 79+05 to 129+37) tested significantly greater than first winter erosion at that site; the respective average values for these periods were 0.153 and 0.019 ft^3/trough/inch of precipitation. As expected, exposure of these slopes to raindrop impact and surface flows produced by spring and summer rainfall was creating greater rill and surface erosion as compared to the winter season.

A decline in fill slope erosion occurred after road construction. The successive decreases in sediment produced from these slopes from the first summer through the third summer (Figure 2) indicate a trend towards stabilization. First summer nonadjusted mean sediment yield (1.14 ft^3/trough) on the fill slopes below the rock surface section, treatment 1, height class 1 (station 0+00 to 79+05) was statistically greater than the mean sediment yield (0.15 ft^3/trough) from the third summer at that site.

The degree of fill slope erosion increased with height class (Figure 3). Statistical differences were not apparent, however the trend towards increased sediment yields from a greater height class is indicated by the data. One atypical result occurred when erosion from height class 1 (0.060 ft^3/trough) during the first summer of data collection was significantly greater than

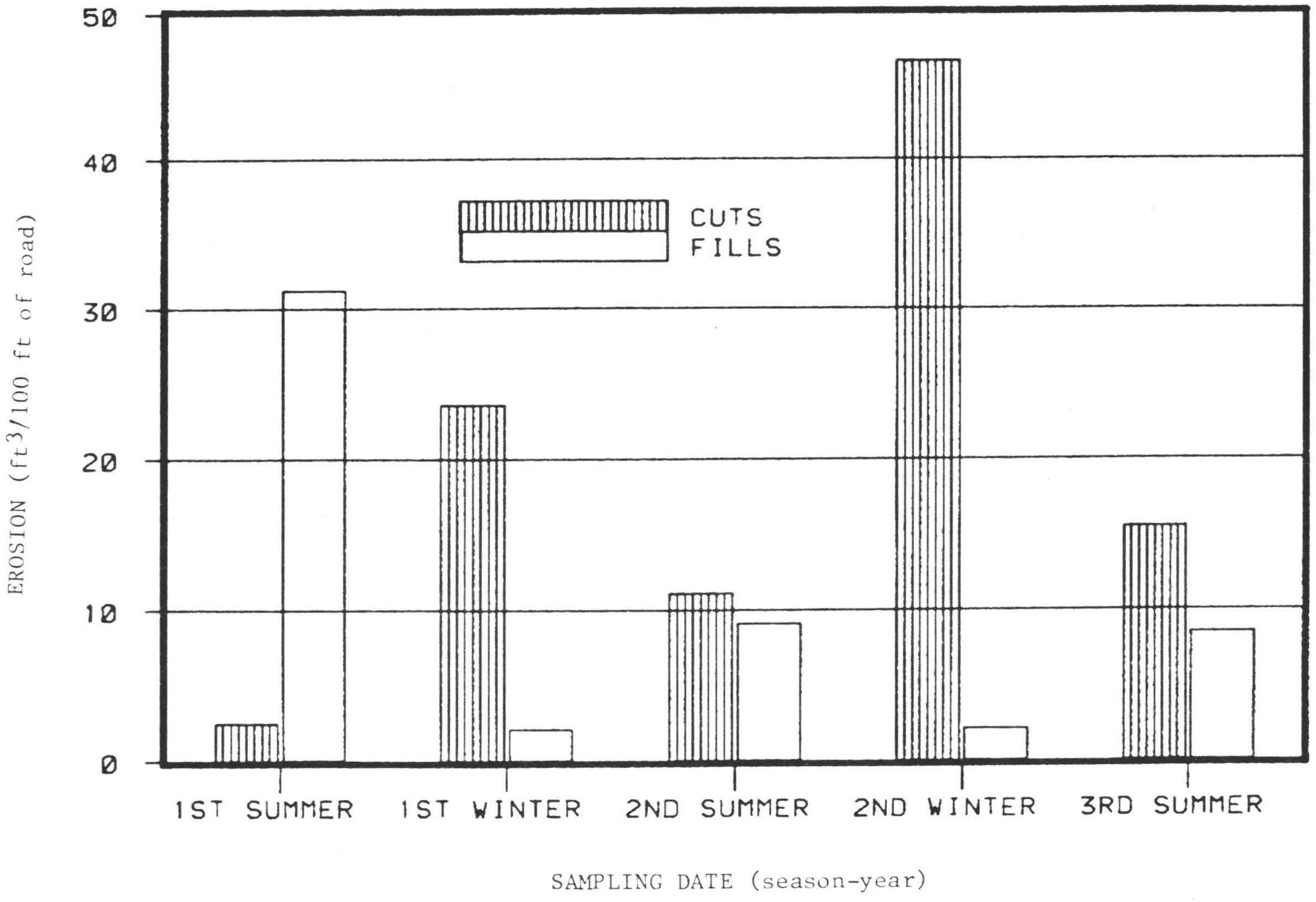


Figure 2. Average cut and fill slope erosion for the summer and winter periods.

class 3 (0.003 ft^3/trough) for that site. Perhaps a site specific anomaly such as gully influence was occurring on the class 1 plots thus producing higher sediment yields. To better represent the differences in erosion between height classes a ratio was developed between class 1 and classes 2, 3 or 4 for each road segment. In the cases where class 4 data were not available, this class was assumed to be the same as class 3. The ratios were summed and divided by the number of road segments (6). Classes 2, 3 and 4 were greater than class 1 by factors of 7.7, 17.5, and 19.5, respectively.

The road segments with similar conditions except for slope treatments were located at stations 129+37 to 194+00 (no treatment) and stations 194+00 to 238+70 (hydroseed only). These road segments were constructed with native soil surfaces. The first summers erosion for these segments were quite different. Sediment from the control section for that period was 2.005 ft^3/trough as compared to 0.020 ft^3/trough for the hydroseed area. However, statistical significance was not supported, partially due to high variance about the means and small sample size. The differences between the weighted averages for total fill slope erosion for these two treatments (59.71 ft^3/100 ft, control and 33.10 ft^3/100 ft hydroseed, Table 4) indicate that slope stabilization was greater on the hydroseeded site.

Significant differences between erosion on fill slopes protected by windrows versus those without windrows were not detected. However, large differences in fill erosion did exsit between the two treatments as illustrated in Figure 4. The stations between 0+00 and 79+05 that were unprotected by windrows produced sediment yields greater than protected sites by factors of 13.8 and 70.2 for classes 1 and 2, respectively.

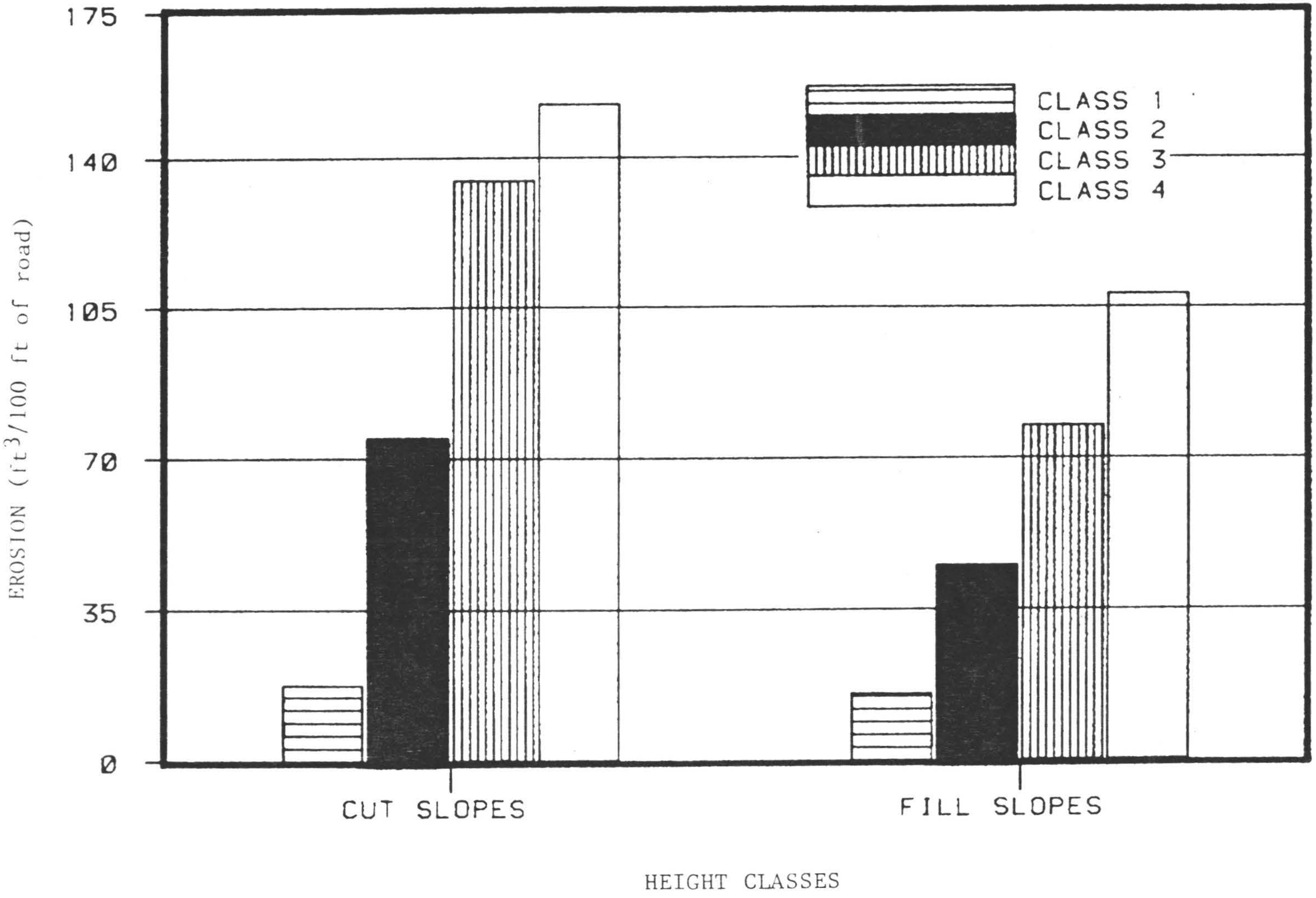


Figure 3. Average cut and fill slope erosion as related to height class.

Table 4. Total fill slope erosion by height category as of mid summer 1980 for the Horse Creek roads.

		Height Category					
Road	Station	1	2	3	4	Weighted averages	Installation date
		------ft^3/100 ft of road------					
9704	0+00-79+05	39.11	78.91	63.50	-	53.06	8-10,11-78
9704	79+05-129+37	9.76	34.90	211.60	-	38.27	8-29-79
9704	129+37-194+00	16.43	73.57	52.41	150.13	59.71	10-2-79
9704	194+00-238+70	5.70	24.84	42.33	60.68	33.10	10-2-79
9708	0+00-73+15	0.62	18.45	42.46	-	12.15	8-31-78
9709	0+00-64+48	21.69	38.84	52.50	120.00	38.43	9-27-78

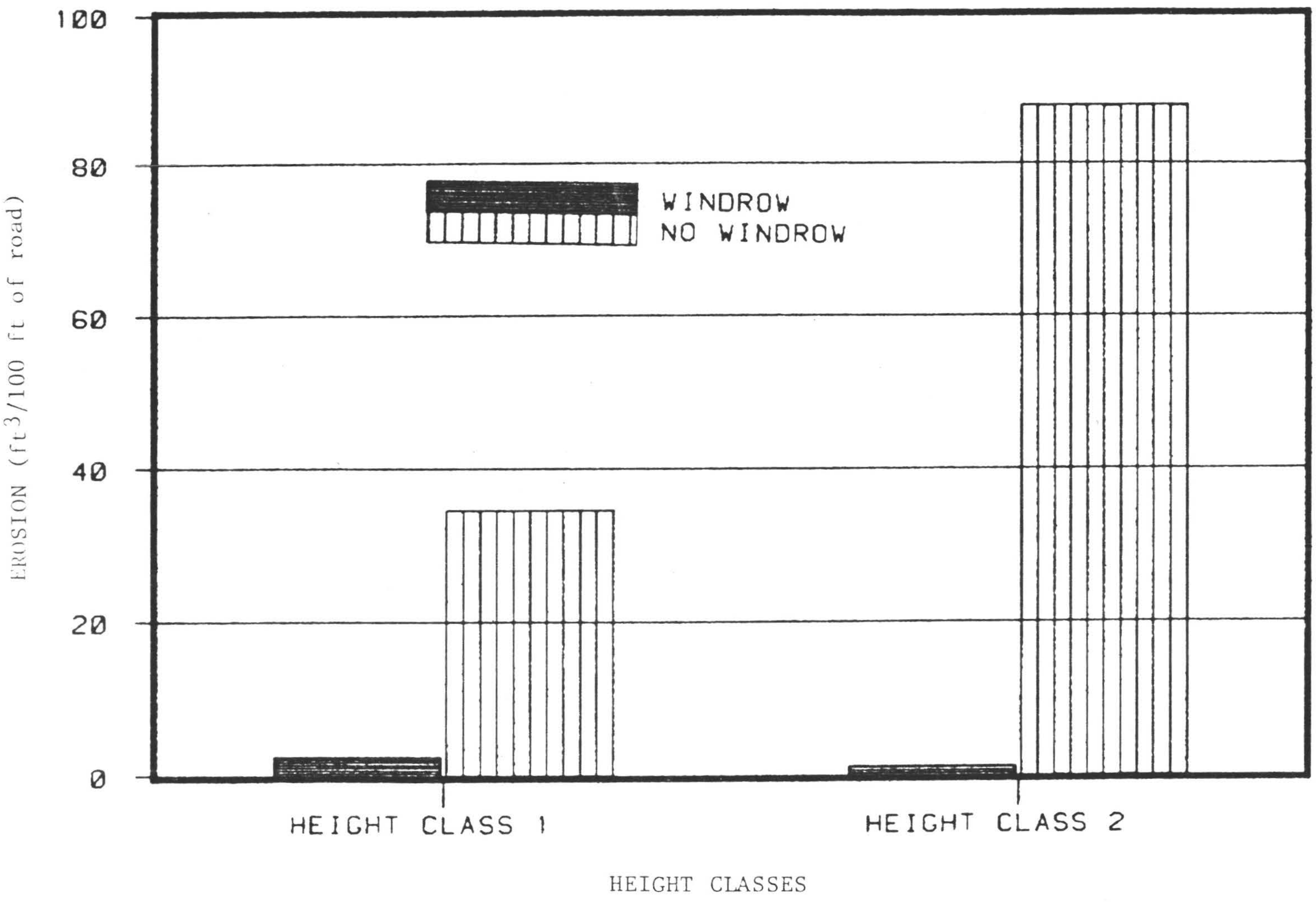


Figure 4. Erosion on windrowed and nonwindrowed fill slopes as related to height class.

CHAPTER 4

CUT SLOPE EROSION

INTRODUCTION

Sediments produced from road cut slopes have the potential for producing adverse impacts on the water and sediment flow from the road-watershed systems. Eroded cut slope material is deposited directly into drainage ditches or adjacent road surface. These detached sediments are subsequently stored at these locations or transported via the road drainage system to downslope watershed surfaces or stream channels. The presence of significant quantities of these deposited sediments in the ditch network can hinder drainage of the road system resulting in accelerated erosion on road and fill slope surfaces.

METHODS

Cut slope erosion was measured with four-foot long traps constructed of 18 gauge, flattened, expanded metal with wood bracing. The metal was lined with 200 micron polyethylene mesh which traps debris but allows water passage.

Installation was conducted by incising the toe of the cut slope with a planting bar. The trap was then placed four inches in the incision and anchored with ½ inch diameter steel reinforcing bar. Spikes were then driven at several locations about ten inches above the trap and flush with the ground to establish a baseline for volume estimation.

Sites for cut slope traps were selected in the same manner as described for fill slope troughs (Chapter 3). Installation and sampling of cut slope traps were also conducted at times similar to those for fill slope troughs.

Observation of summer 1980 data indicated that trap measurements were over estimating cut slope erosion. Apparently not all the soil moving on an exposed cut was being completely transported from the slope. An over estimation was calculated for each trap by determining the geometric shape of the slope adjacent to it. The over estimate was distributed back over time according to the percent of total erosion at each sampling date.

Surface erosion and mass wasting have been observed to occur on the cut slopes. However, unlike the fill slopes, much of the surface erosion from cut banks appears to occur as dry raveling; i.e. movement of individual soil particles down slope due to gravitational forces.

Many of the assumptions pertaining to erosion trends for cut slopes were the same as for the fill slope analysis. Differences were postulated to exist between seasons, successive seasons, height classes, stabilization treatments, and also between cut slopes and fill slopes. Construction differences of cut slopes between standards were considered insignificant on impacting erosion rates, therefore testing for these parameters was not conducted.

The Student's t-test with unequal variances, unpaired observations, and $\alpha = 0.10$ was used for testing for statistical differences between means. High variance about the means and small sample size again contributed to lack of significance for a majority of the tests.

Statistical tables for cut slope erosion are presented in Appendix 2. The common unit of comparison chosen for incomplete seasons was erosion unitized with time. This unit (ft^3/trap/week) was determined by dividing the amount of erosion during the period by the number of weeks in the period. The discussion of cut slope erosion is limited to road 9704.

RESULTS AND DISCUSSION

Contrary to the fill slope erosion trends, reduction in cut slope erosion with time did not occur (Figure 2, Chapter 3). However, a difference in sediment yields between summer and winter periods were observed with winter yields being greater; the reverse of fill slope erosion trends.

Erosion, unitized with time on class 1 traps for stations 129+37 to 238+70 during the winter of 1979, was significantly greater than summer 1980 erosion. The respective average sediment yields for those periods were 0.017 and 0.006 ft^3/trap/week.

Slope height appeared to affect the degree of erosion on the cut slopes. The trend for increased erosion with greater slope height is indicated in Table 5. Analysis of the height class erosion ratio for the cut slope data, as explained in the fill slope section indicates that classes 2, 3, and 4 exceed class 1 by a factor of 5.5, 7.5, and 10.0, respectively. Figure 3 (Chapter 3) illustrates average erosion by height class for cut banks.

Average cumulative erosion of treatment 1, stations 79+05 to 129+37 and treatment 4, stations 129+37 to 238+70 were compared to define differences in erosion on treated and nontreated cut slope surfaces. Erosion on class 1 slopes without surface protection (0.60 ft^3/trap, treatment 4) was significantly greater than on the sites protected with hydroseed and mulch (0.16 ft^3/trap, treatment 1).

Cut Slope and Fill Slope Comparison

Cut slope and fill slope data were compared in an attempt to identify differences in the degree of erosion with time and level of stabilization treatment. Sediment yields on road 9704, stations 79+05 to 129+37, treatment 1, were significantly greater for height classes 1 (1.14 ft^3/trough)

Table 5. Total cut slope erosion by height category as of mid-summer 1980 for the Horse Creek roads

		Height categories				Construction
Road	Station	1	2	3	4	year
		----ft^3/100 ft of road----				
9704	0+00-79+05	20.19	173.93	145.45	-	1978
9704	79+05-129+37	4.07	55.76	-	-	1979
9704	129+37-185+10	22.75	79.66	222.46	262.14	1979
9704	185+10-238+70	13.40	10.89	86.25	-	1979
9708	0+00-73+15	17.80	48.31	135.14	-	1978
9709	0+00-64+48	27.75	78.96	162.87	232.51	1978

and 2 (1.82 ft^3/trough) on fill slopes during the first summer after construction as compared to cut slopes, class 1 (0.0 ft^3/trough) and class 2 (0.04 ft^3/trough). The reverse trend occurs during the winter. As illustrated in Figure 2 rates of erosion on fill slopes decline rapidly with time after the first summer, however, erosion rates on the cut slopes remain higher in winter and comparatively lower in the summer. Statistical analysis did not support significant differences between winter erosion on cut and fill slopes however, analysis of the observed data (Table 6) suggest that these differences are real.

Cumulative erosion from cut banks tends to be greater than from fill slopes (Table 7). Apparently the fill slopes were stabilizing during the period of record more rapidly than the cut banks. The difference between cut and fill accumulated erosion may become more apparent with time.

Table 6. Seasonal erosion of cuts and fills by height category for road 9704.

Seasonal Erosion (ft^3/trap)

Station	Class	Summer Cuts	1978 Fills	Winter Cuts	1979 Fills	Summer Cuts	1979 Fills	Winter Cuts	1980 Fills	Summer Cuts	1980 Fills
0+00 to 79+05	1	0	1.14	0.14	0.01	0.01	0.18	0.37	0.11	0.01	0.15
	2	0.04	1.82	1.75	0.24	1.22	0.69	3.34	0.02	1.22	0.59
	3	0	0.54	0.28	0.05	1.39	0.55	3.89	0.04	1.39	1.00
79+05 to 129+37	1					0.03	0.29	0.09	0.05	0.04	0.05
	2					0.07	0.58	1.36	0.50	0.61	0.32
	3					1/	3.01	-	3.25	-	2.20
129+37 to 184+10	1					0.01	0.06	0.89	0.22	0.01	0.38
for cuts	2					0.13	0.09	2.30	0.88	0.75	1.72
129+37 to 194+00	3					0.61	0.003	5.78	0.85	2.67	2.14
for fills	4					0.94	2.005	4.74	1.20	4.80	2.30
184+10 to 238+70	1					0.07	0.10	0.41	0.05	0.06	0.08
for cuts	2					0.05	0.09	0.32	0.40	0.06	0.53
194+00 to 238+70	3					0.27	0.002	2.64	1.02	0.54	0.66
for fills	4					-	0.002	-	1.13	-	-

---

[1] no traps in that category

Table 7. Total mean slope erosion by height category, as of mid-July, 1980 from Horse Creek roads constructed in the summer of 1978.

	Height category 1	 2	 3	Weighted average
	---ft^3/100 ft of road--			
Cuts	21.91	100.40	147.82	68.54
Fills	20.47	45.40	52.82	34.55
% Difference	7.0	121.2	179.9	98.4

CHAPTER 5

CUT SLOPE AND FILL SLOPE MODELING

INTRODUCTION

One of the continuing objectives of the Horse Creek Administrative Research Project is to develop models for predicting sediment yields produced by road construction and maintenance in the Meadow Creek System. Some initial model development was attempted in this study with the past two years of road data from Horse Creek.

METHODS

Cut and fill slope data were plotted for accumulated erosion versus time by height class. Similar plots were made for accumulated erosion versus precipitation. Cut and fill slope erosion rates were also plotted with time.

Several linear and non-linear mathematical functions were tested in an attempt to describe accumulated erosion and erosion rates for cut and fill slopes. Model selection was conducted by utilization of the General Linear Models procedures of the Statistical Analysis System.

Data for winter erosion were excluded from these analysis because the dominant factors affecting sediment detachment and transport are different during snowmelt runoff as compared to rainstorm events.

RESULTS AND DISCUSSION

Application of the various models to accumulated fill slope erosion data provided insight into selection of the equation which best described the changes in accumulated erosion with time. The model which best described this relationship was of the form:

$$Y = \beta_o + \beta_1 X + \beta_2 \ln X + \varepsilon$$

Where Y = cumulative erosion (ft^3/100 ft of road)

X = number of days since trough installation

β_o, β_1, β_2 = regression coefficients

ε = error

The equations developed for predicting fill slope erosion for roads 9704 and 9708 as a function of time and precipitation are presented in Tables 8 and 9, respectively. The coefficient of determination was greater than 0.90 for 12 of the 16 equations, with the lowest R^2 being 0.86. Figure 5 illustrates a plot of the regression equations developed for accumulated erosion as a function of fill slope height class for road 9704 stations 0+00 to 79+05. The fill slope data on road 9709 did not appear to have a definable relationship. Periods of missing data most likely contributed to this lack of an identifiable pattern, therefore modeling of these data was not attempted.

Several models were applied to the cut slope accumulated erosion data, however, because of poor statistics of fit (low R^2 and high probability of a greater F value) these attempts were abandoned.

The equation selected as best describing the fill slope erosion rate data was of the form:

$$\ln Y = \beta_o + \beta_1 \ln X + \varepsilon$$

Where:

Y = erosion rate (ft^3/100 ft/day/inch precipitation)

X = number of days since trough installation

β_o and β_1 = regression coefficients

ε = error

Table 8. Regression coefficients and statistical information for the fill slope erosion model: $Y = \beta_o + \beta_1 X + \beta_2 \ell nX$, where X equals the number of days since trough installation and Y equals cumulative erosion in $ft^3/100$ ft of road.

Road	Station	$\hat{Y}$	$\hat{\beta}_o$	$\hat{\beta}_1$	$\hat{\beta}_2$	R^2	F value	Probability of a greater F
9704	0+00-79+05	Wt. Ave.[1]	0.2343	0.0131	5.9061	0.94	71	0.0001
		HC1 [2]	-0.2583	-0.0010	5.6591	0.90	43	0.0001
		HC2	-2.9728	0.0261	8.5957	0.96	102	0.0001
		HC3 [3]	23.4265	0.0861	-5.1399	0.87	30	0.0001
9708	0+00-73+15	Wt. Ave.	1.3489	0.0073	0.8309	0.96	44	0.0019
		HC1	0.3510	0.0015	-0.1315	0.89	16	0.0123
		HC2	-1.5117	0.0178	0.9397	0.96	43	0.0020
		HC3	15.8330	0.0103	2.8697	0.92	22	0.0071

[1] Wt. Ave. = weighted average erosion

[2] HC = height category

[3] This model is based on data from only one fill slope trough.

Table 9. Regression coefficients and statistical information for the fill slope erosion model: $Y = \beta_o + \beta_1 X + \beta_2 \ln X$, where X equals the number of inches of precipitation since trough installation and Y equals cumulative erosion in ft^3/100 ft. of road.

Road	Station	$\hat{Y}$	$\hat{\beta}_o$	$\hat{\beta}_1$	$\hat{\beta}_2$	Correlation coefficient	F value	Probability of a greater F
9704	0+00-79+05	Wt. Ave.[1]	14.5490	0.0733	6.4896	0.91	48	0.0001
		HC1[2]	13.4666	-0.0314	5.8019	0.86	28	0.0001
		HC2	17.5470	0.1290	10.1747	0.94	70	0.0001
		HC3[3]	12.5002	0.8324	-5.2759	0.91	43	0.0001
9708	0+00-73+15	Wt. Ave.	3.6908	0.0655	0.7726	0.93	25	0.0054
		HC1	0.0722	0.0138	-0.1351	0.94	32	0.0035
		HC2	1.3482	0.1585	0.9133	0.94	33	0.0032
		HC3	23.8797	0.1068	2.3520	0.86	12	0.0206

[1] Wt.Ave. = weighted average

[2] HC = height category

[3] This model is based on data from only one fill slope trough.

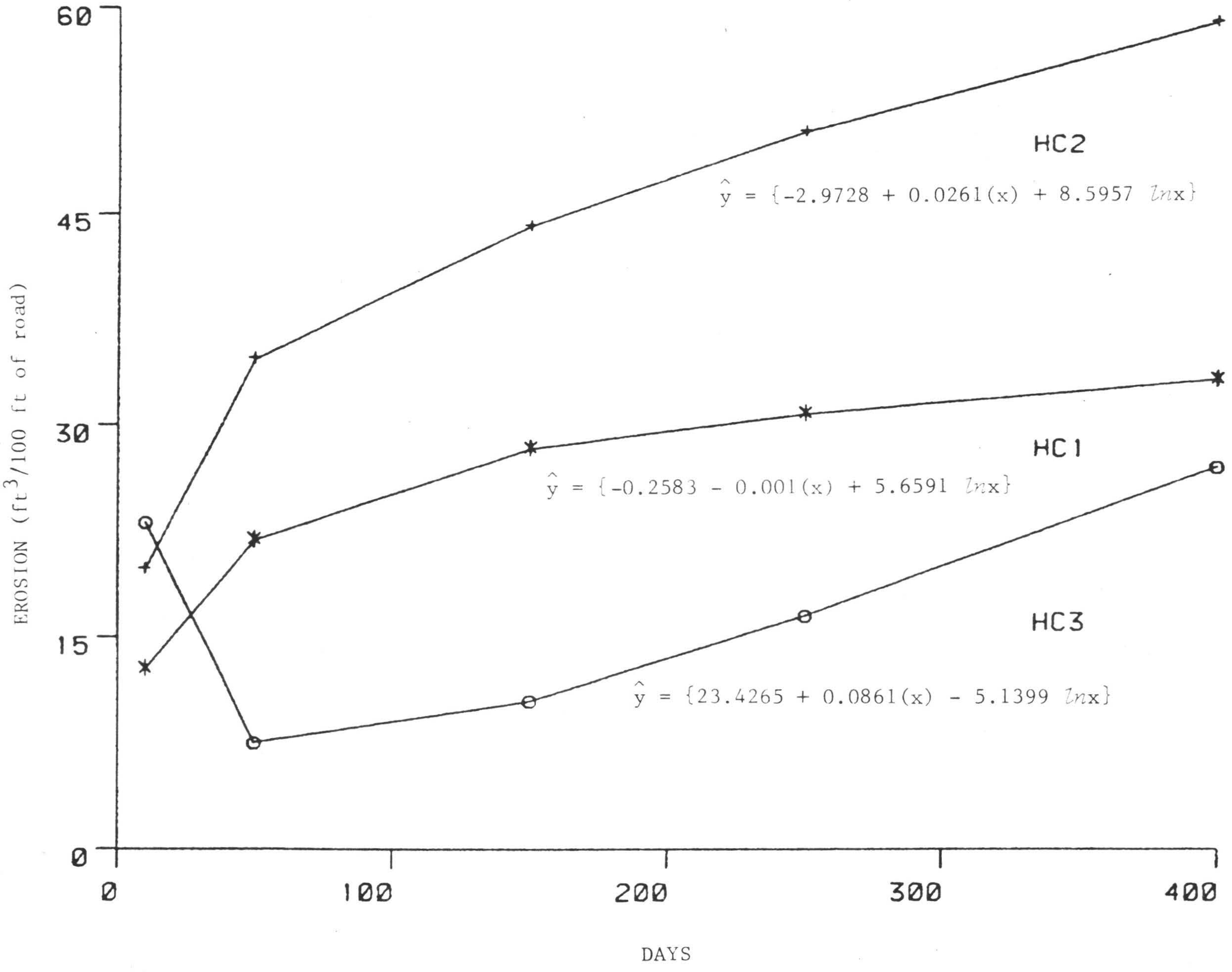


Figure 5. Predicted accumulated erosion on fill slopes as a function of time by height class for road 9704, stations 0+00 to 79+05.

The equations for fill slope rates of erosion are presented in Table 10. Equations for fill slope rates of erosion on road 9709 and for cut slope rates of erosion on all roads were not developed for reasons previously stated. The predictive equation for fill slope erosion rate as a function of days since trough installation is presented in Figure 6.

Comparison with Bogus Basin Model

Megahan (1974) developed a model which expresses road fill slope erosion in tons/mi^2 as a function of time. The model was developed from data collected in the Bogus Basin area which is located in the granitic soils of the Idaho Batholith. The model is expressed in the form:

$$Y = \beta_o t - \beta_1 \{e^{-\beta_2 t} - 1\}$$

Where:

Y = accumulated fill slope erosion (tons/mi^2 of area disturbed)
t = accumulated time since disturbance (days)
β_o, β_1, and β_2 in this specific case = 17.4, 21484.7, and 0.0375, respectively.

The volume of erosion predicted with the Horse Creek model developed in this study for the weighted average fill slope erosion on road 9704, stations 0+00 to 79+05 ($\hat{Y} = 0.2343 + 0.0131\ (X) + 5.9061\ \ell n\ (X)$), at 704 days is 48.18 ft^3/100 ft. road. Assuming a density of 1.787 tons/yd^3 for fill slopes of gnessic material and a total disturbed area of 0.0043 mi^2, the predicted volume extrapolates to 58,620 tons/mi^2. The Bogus Basin model predicts for the same 704 day period accumulated erosion of 33,734 tons/mi^2, which represents a difference of 42% from the Horse Creek model prediction.

A comparison of the prediction equations are presented in Figure 7. Some of the major reasons attributed to these differences in predicted fill

Table 10.--Regression coefficients and statistical information for the fill slope erosion rate curves. The model is of the form $\ell nY = \beta_o + \beta_1 \ell nX$ where X = number of days since trough installation and Y = erosion rate, ft^3/100 ft/day/inch of precipitation.

Road	Station	Erosion Rate	Regression Coefficients				Probability of
		$\hat{Y}$	$\hat{\beta}_o$	$\hat{\beta}_1$	R^2	F value	a greater F
9704	0+00-79+05	Wt. Ave.[1]	3.5047	-1.5619	0.95	121	0.0001
		HC1[2]	4.0009	-1.8261	0.90	63	0.0001
		HC2	3.6424	-1.4879	0.94	115	0.0001
		HC3	0.2402	-0.9645	0.67	12	0.0134
9708	0+00-73+15	Wt. Ave.	3.4358	-1.9026	0.96	94	0.0023
		HC1	mean = -9.9598 st. dev. = 0.2843				
		HC2	-0.9725	-0.9792	0.70	7	0.0800
		HC3	6.8211	-2.4410	0.96	80	0.0029
9709	0+00-64+48		----models not developed----				

[1] Wt.Ave. = weighted average erosion rate

[2] HC = height category

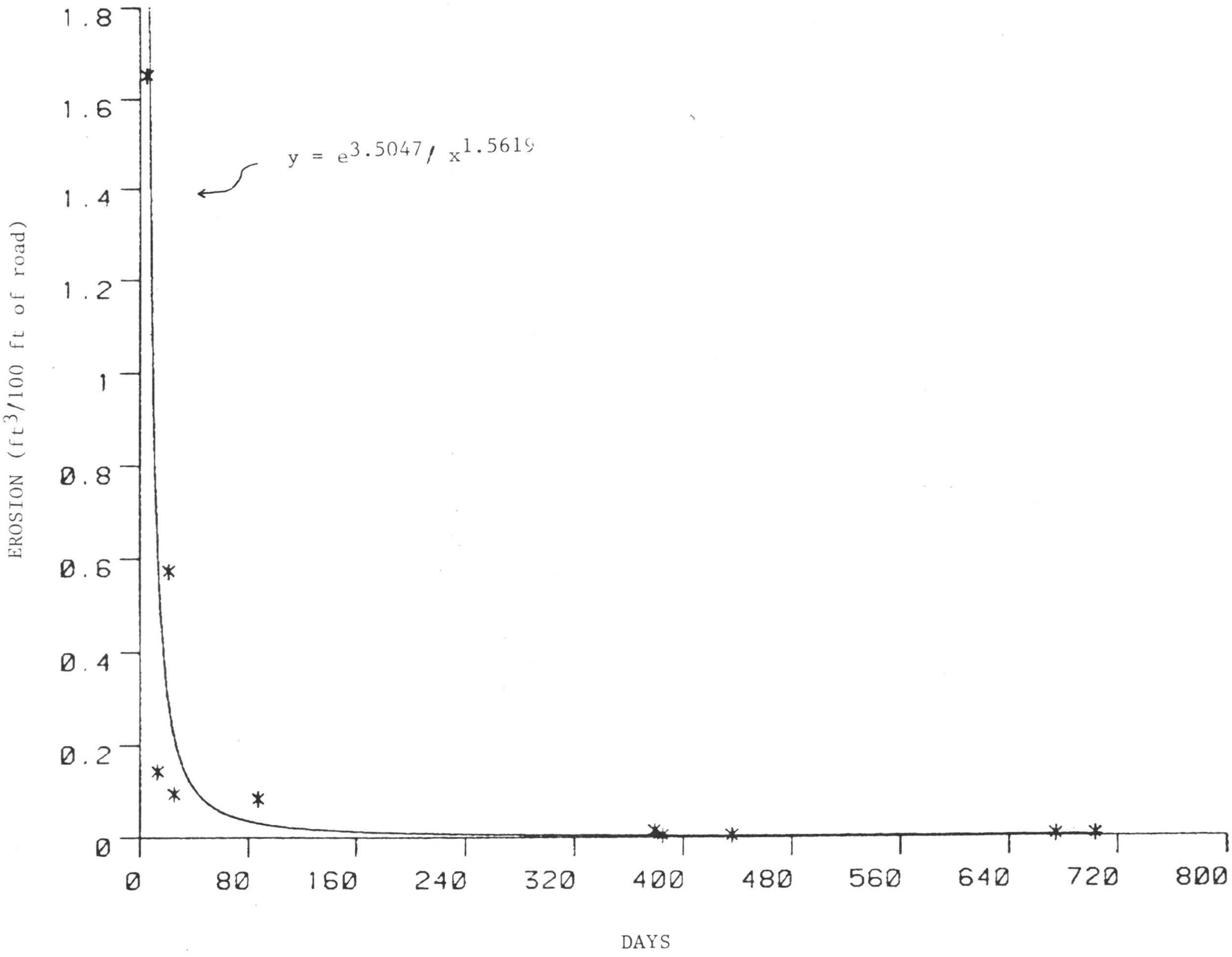
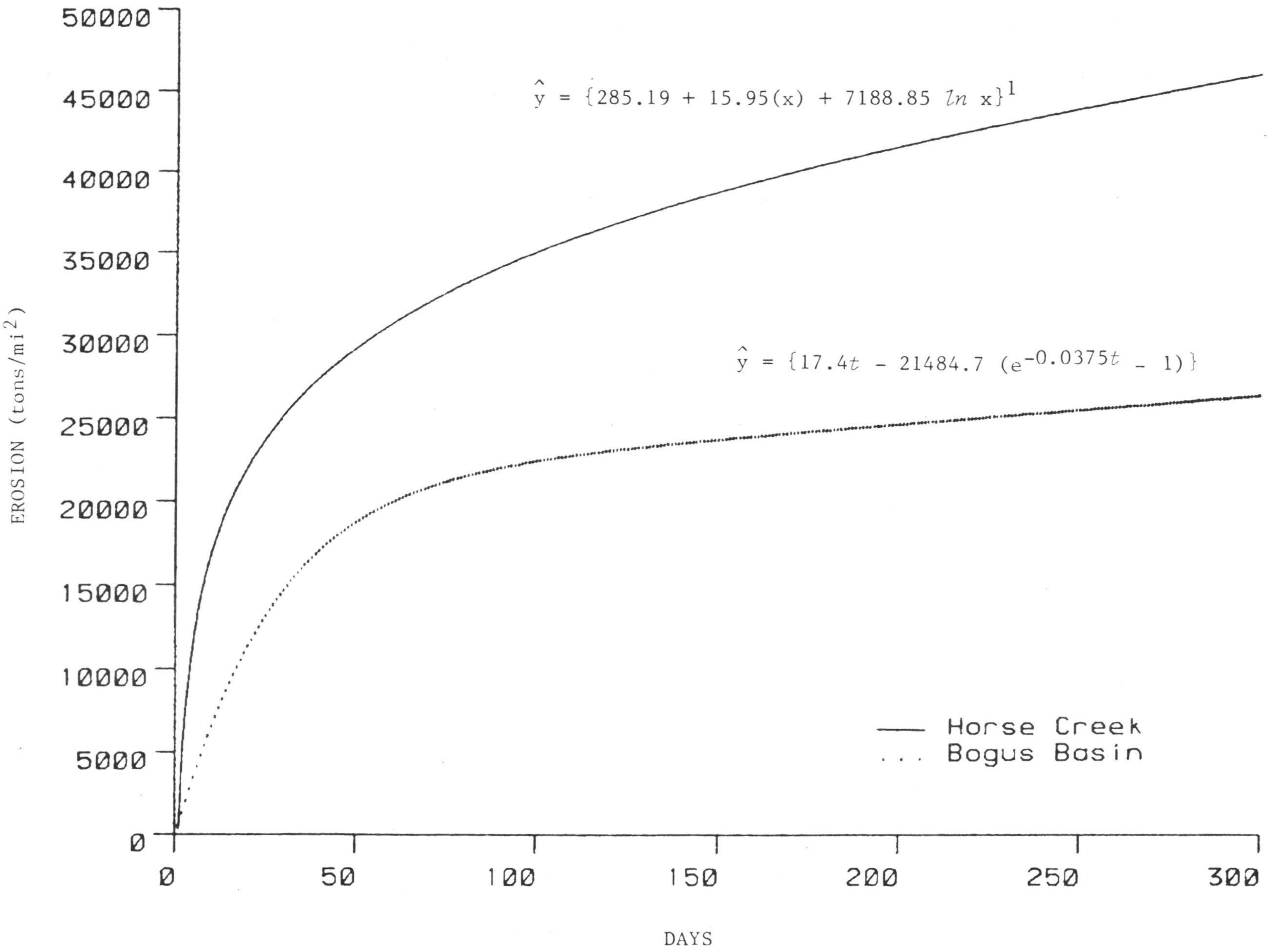


Figure 6. Fill slope erosion rate as a function of days since trough installation for road 9704, stations 0+00 to 79+05.



[1] Horse Creek model with unit adjustment.

Figure 7. Comparison of the Bogus Basin and Horse Creek fill slope erosion models.

slope erosion include; (1) differences in parent material, therefore, different erodability characteristics, (2) height class distributions used for model development were not specified in the Bogus Basin study, thus, the validity of comparison is related to the assumption that similar height classes are respresented, and (3) the equations were developed for different roads, thus the model regression coefficients are most representative of the individual road conditions and erosion rates.

CHAPTER 6

RILL AND GULLY EROSION OF FILL SLOPES

INTRODUCTION

The original technique to quantify fill erosion included measurement of sediment delivered to four-foot long troughs placed along the toe of the fill slope. However, as the result of the first few convective storms, rills and gullies began forming in the new fills. The trough sampling intensity was too low to adequately sample such a variable process. Therefore, the decision was made to inventory all gullies and rills each fall and spring to better quantify fill erosion.

METHODS

Rill and gully erosion of the fill slopes on road 9704, stations 0+00 to 79+05 was quantified each fall and spring following road construction. The fills were constructed with a 1½:1 slope. Filter windrows were placed at live water crossings along the toe of the fill for this section of road. Approximately 1190 feet of fills were protected with windrows, which were put in place as the road was constructed. In the fall the slopes were seeded, hyrdomulched and fertilized.

Rills with an estimated volume of ≤ 1.0 ft^3 were counted. The volume was measured or estimated for all rills > 1.0 ft^3. The width and depth of a rill at the top and bottom of the fill slope plus its length was measured and used to determine volume. After many measurements of rill volumes the crew became reasonably accurate at estimating volumes. Subsequent sampling included estimates of volume with frequent measurement checks. The accuracy of the erosion estimates by this method is considered to be ± 15 percent.

Additionally, the downslope travel distance of eroded material was measured for each fill along with the slopes of the forest floor and fill surfaces. Field notes were made on; (1) the disposition of transported material, (2) visible contributions of overland flow from the road surface, and (3) special fill slope treatments.

Slumping of the saturated fill material was common during the first spring snowmelt season. Therefore, additional notes were made on the location of slumping activity during the rill surveys. For those slumps which could possibly contribute to instream sediments down gradient from the fill slope, measurements were made of void volume at the head of the slump, plus transport distance of the dislodged material. No attempt was made to measure the volume of the slumped material leaving the fill slope.

RESULTS AND DISCUSSION

Erosion Volumes

Total rill erosion from the time of road construction to the fall of 1980, (approximately two years) amounted to 1895.9 ft^3 or 23.98 ft^3 per 100 feet of road length. Using an estimated bulk density of 1.24 gm/cc [1/] this value converts to 29182 $tons/mi^2$. Approximately 44 percent of the total eroded fill material left the fill slope during a six week to two month period of time between road completion and the first rill survey (Figure 8). The slopes had not been hydromulched and seeded during this period and several intense rainstorms easily eroded the recently deposited fill material. August 1978 was unusually wet as evidenced by 2.74 inches of rain between August 12th and 22nd.

Slumping of fill material was common in the spring of 1979, nine months

[1/] Gospel Hump data for similar soils.

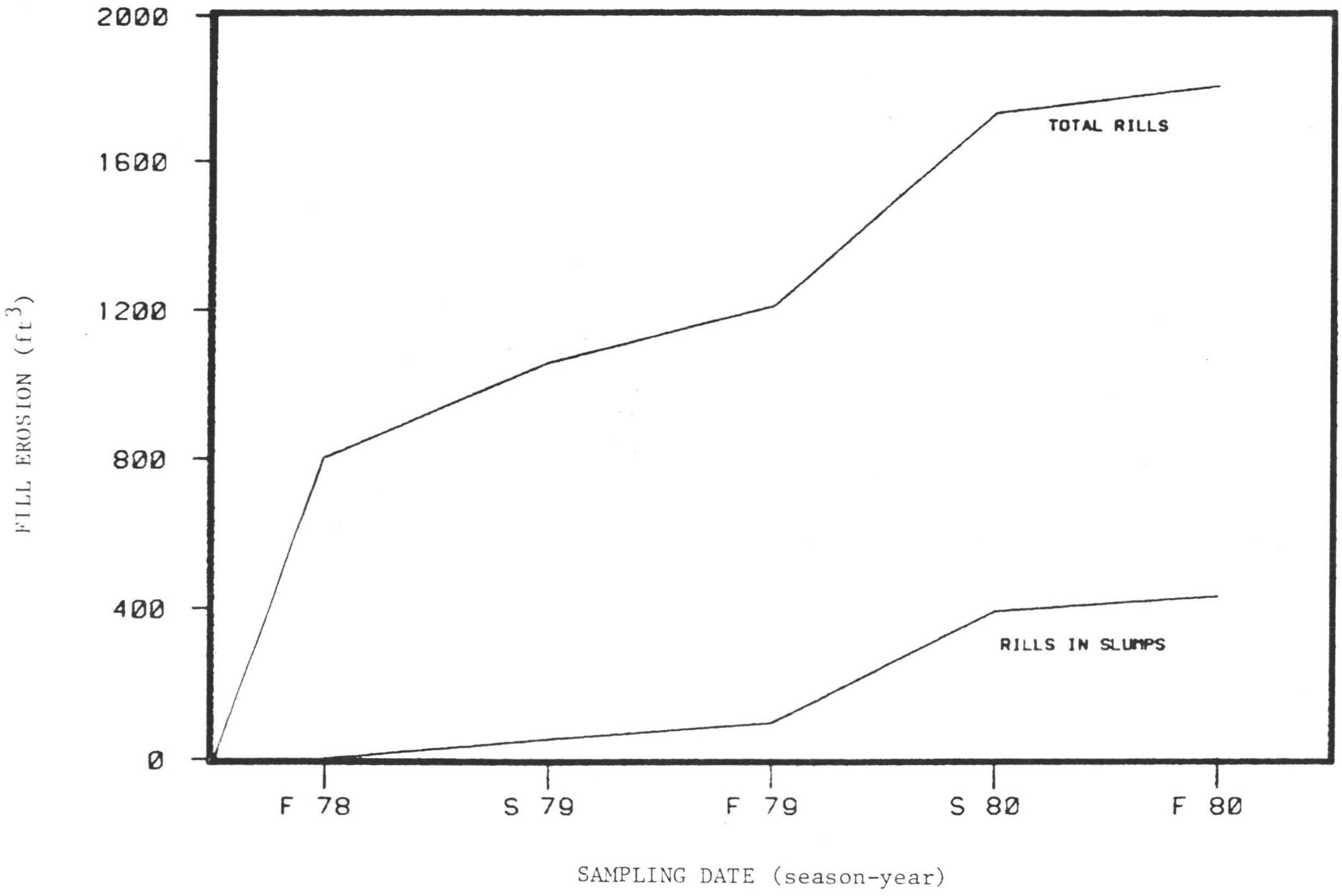


Figure 8. Total rill erosion and rill erosion in slumped material over time for road 9704, stations 0+00 to 79+05.

following road construction. Approximately 11% of the length of road exhibited slumping to various degrees. Although slumping was occurring trafficability of the road was not adversely affected, in fact many of the slumps were small and did not leave the fill slope. Several slumps involved displacement of 20-60 ft^3 of material. The slumping activity partially nullified the stabilizing effects of hydromulching and seeding by exposing bare mineral soil surfaces to rain and surface runoff. Slumped material was approximately 5% of the total rill erosion during the spring of 1979. Rill erosion in the slumped material (432 ft^3 of material) accounted for 23% of the total rill erosion by the fall of 1980 (Figure 8).

Figure 9 illustrates the time trend in cumulative fill erosion as determined from collection trough data and from the rill surveys. The trap data indicates more than twice as much fill erosion as compared to the rill surveys. As of fall 1980 cumulative trap and rill erosion values were 53 and 24 ft^3/100 ft. of road length, respectively. The rill survey erosion estimates are comparatively lower because they do not include sheet erosion or material transported off the slopes in slumps. Also, total trap collection length measured less than one percent of the total length of fills; therefore, erosion estimates from these data are very sensitive to a single rill influencing a trap. The true value of erosion probably falls somewhere between the rill survey and fill trough estimates. However, the rill volume estimations should be more accurate because the total length of road was measured. When estimates of slump erosion volumes are added to the rill erosion volumes the values increase to within 10-15% of the trough estimates.

Transport Distance

The downslope transport of sediment below the rills and gullies in the

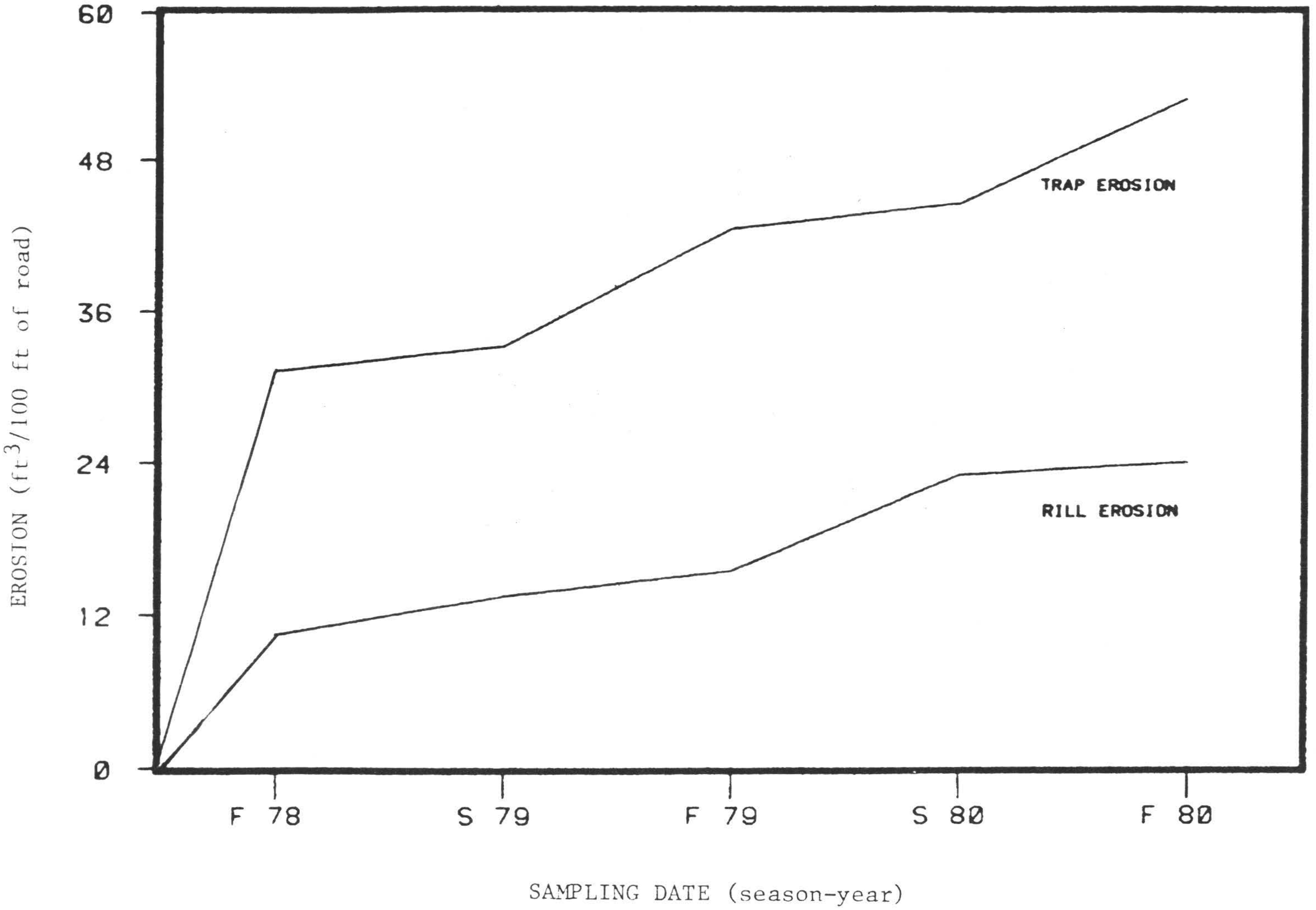


Figure 9. Fill erosion over time for two methods of quantification on road 9704, stations 0+00 to 79+05.

fill slope was extremely variable (Table 11). The maximum transport distance measured was 150 feet. Those gullies that were below or adjacent to relief culverts tend to have greater travel distances below the fills. The rills above filter windrows did not transport material below the windrows during the first year. The average travel distance below the windrows as of the fall of 1980, was 3.8 feet. Rills and gullies in slumped material had longer travel distances (41.4 ft.) than those on nonslumped fills (24.2 ft.), for the same period. Along the total length of road, 7905 feet, with 6 stream crossings, only five gullies reached live water. This lack of disturbance of stream channel integrity was primarily attributed to the protection of the fill slopes with filter windrows at each of the crossings.

Stepwise regression techniques were used to develop predictive equations for downslope transport of material below the fills. Modeling was limited to gullies formed in nonwindrowed fills which did not reach live water and were not influenced by relief culvert drainage.

The independent variables were: volume of the rill in cubic feet (V); percent slope of the fill (FSL); percent slope of the forest floor below the fill (FORSL); height category of the fill slope (HCAT) where categories 1, 2, 3 and 4 are fill slopes with vertical heights of 0-10 ft, 20-30 ft, and greater than 30 ft, respectively; and a dummy variable indicating whether or not the rill was visibly caused by surface runoff from the road surface (RO).

Table 12 lists the regression equations developed for predicting downslope transport of fill material below rills and gullies. A probability of a greater F value of less than 0.1 was required for inclusion of each independent variable, in the model. The resultant coefficients of determination were low, ranging from 0.26 to 0.47, indicating that much of the

Table 11. Mean travel distance of fill material below rills and gullies for different fill conditions for road 9704, stations 0+00 to 79+05.

Sampling Date	Fill Condition Code 1/															
	3		5		6		7		8		9		10		Total	
	Number of Rills/Mean Travel Distance (ft.)															
Fall 1978	2	73.5					16	0.0	7	59.1	7	62.9	208	8.1	240	11.2
Spring 1979	1	122.0			8	15.4	35	0.0	10	65.4	4	108.3	182	12.2	240	14.9
Fall 1979	1	122.0	2	-	15	38.0	37	2.5	12	69.5	6	83.3	168	14.6	241	18.9
Spring 1980	1	122.0			29	35.6	45	3.8	14	64.1	5	67.6	154	23.2	248	24.7
Fall 1980	1	122.0			34	41.4	45	3.8	15	59.8	5	67.6	148	24.2	248	26.3

1/ 3 = gully below culvert outfall; 5 = no distance data recorded;
6 = rill or gully in slumped material; 7 = rill or gully above filter windrow;
8 = combines with culvert outfall; 9 = reaches a live stream;
10 = all other situations

Table 12. Stepwise regression coefficients and statistical information for the transport distance predictive equations for road 9704, stations 0+00 to 79+05.

Sampling Date		$\hat{\beta}_0$	Variable1/	$\hat{\beta}_1$	Variable	$\hat{\beta}_2$	Variable	$\hat{\beta}_3$	Variable	$\hat{\beta}_4$	R^2	Prob > F
Fall 1978		9.40	V	1.83	RD	9.05					0.47	0.0001
Spring 1979	1	16.07	V	0.77	RD	18.51					0.28	0.0001
	2	-8.24	V	0.72	FSL	0.40	RD	19.84			0.32	0.0001
Fall 1979		2.54	V	1.18	FORSL	0.51					0.24	0.0001
Spring 1980	1	13.35	V	0.61	HCAT	10.42					0.26	0.0001
	2	9.06	V	0.56	RD	20.82	HCAT	11.92			0.31	0.0001
	3	-9.20	V	0.58	FORSL	0.49	RD	20.34	HCAT	11.66	0.35	0.0001
Fall 1980	1	13.18	V	0.61	HCAT	11.30					0.26	0.0001
	2	-5.39	V	0.63	FORSL	0.50	HCAT	10.94			0.29	0.0001
	3	-8.64	V	0.58	FORSL	0.49	RD	18.46	HCAT	12.29	0.32	0.0001

1/ Independent variables: V = volume of rill (ft^3), RD = road contribution dummy variable,
HCAT = height category of the fill slope, FSL = slope of fill (%),
FORSL = slope of forest floor (%).

variation is not being explained by the model. The poor fit of the regression model can partially be explained by the omittance of variables which can greatly influence transport. For example, the type or density of obstructions (i.e. brush, depressions, etc.) below the fills were not measured thus, not included in model development.

The most important variable in all of the regressions was the volume of the gully; transport distance increased with increasing gully volume. The road contribution variable was also important; with transport distance increasing if the road surface was contributing surface runoff.

Regressions developed for the second year after road construction include the variables of fill slope height category and percent slope of the forest floor. Apparently the initial transport of material is primarily influenced by the volume of water acting on the fill slopes while subsequent increases in transport distance are also influenced by road design and topography variables.

The volume of transported fill material deposited within downslope distance categories was not measured. However, if the assumption is made that deposition is uniform along the travel distance, then volumes with distance categories can be approximated. Figures 10 and 11 show the percentage of material passing given downslope distances. Rills reaching live water, above windrows, or influenced by relief culvert outflow were not used in this analysis. The percentage of material passing a given distance increases with time as does the actual volume. Two years following construction, 73% of the material is still within 50 feet of the toe of the fill. This amounts to approximately 332 ft^3 of material being transported greater than 50 ft.

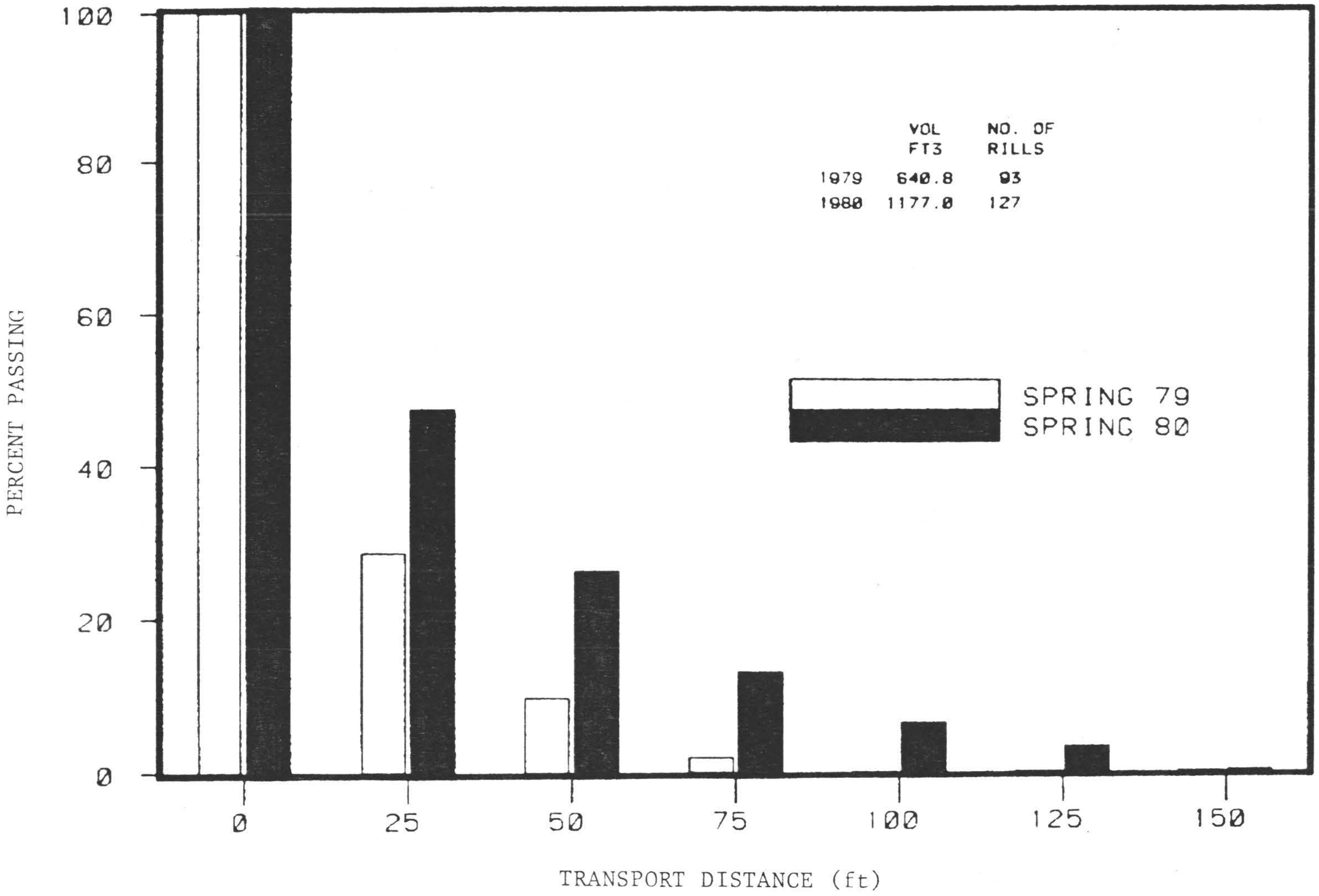


Figure 10. The percentage of material passing a defined downslope distance for the spring of 1979 and 1980.

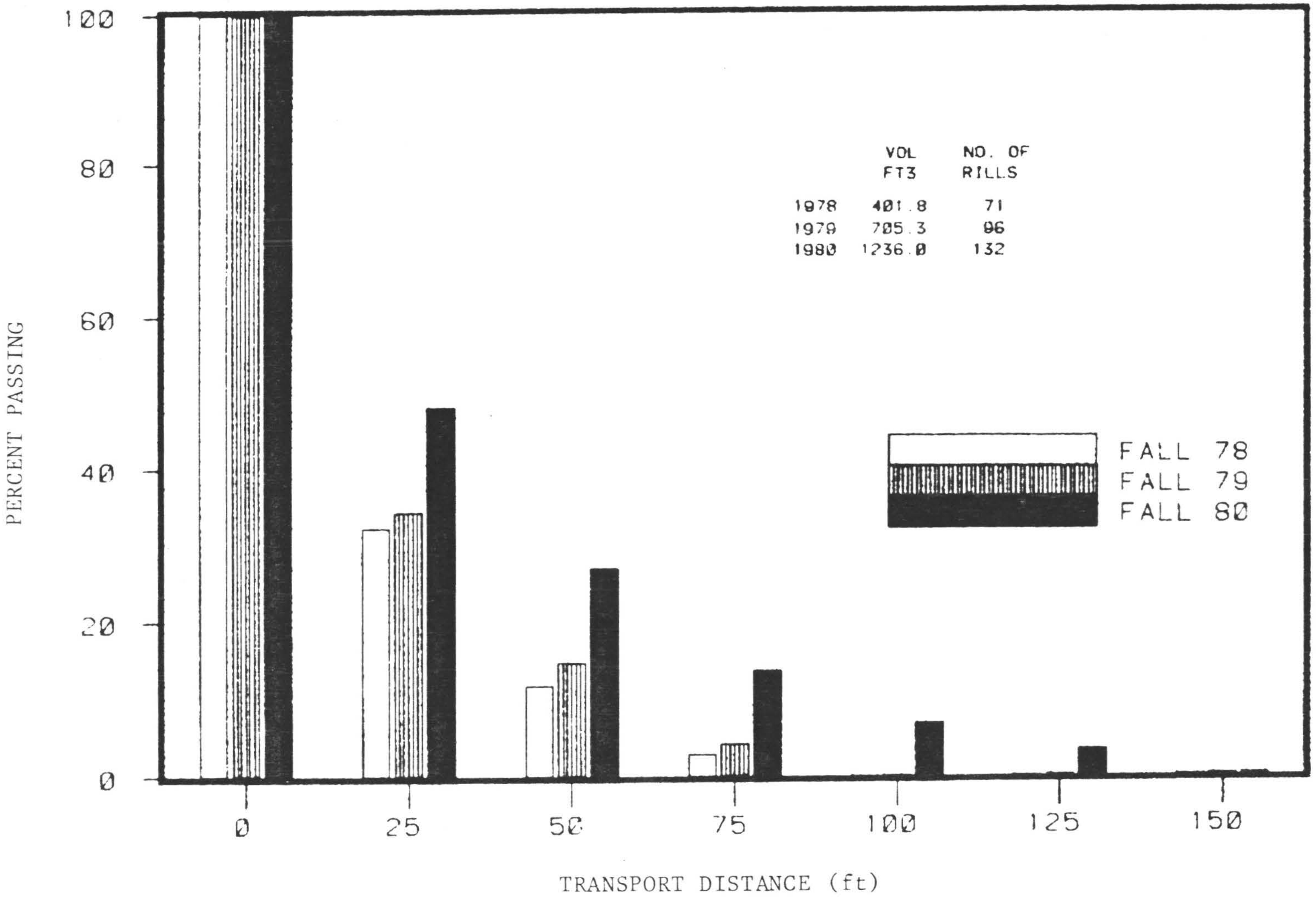


Figure 11. The percentage of material passing a defined downslope distance for the fall of 1978, 1979 and 1980.

CHAPTER 7

DITCH EROSION

INTRODUCTION

The purpose of a ditch profile analysis was to aid in determining the origin, deposition, and movement of sediment from specific portions of the road prism--cut, ditch, roadbed, and fill--and to define the relative contribution of the ditch to total sediment load.

A complete ditch profile analysis will eventually be used to evaluate differences in erosional processes between road standards, roads with different surfacing, different cut slope heights, cut slope treatments, and ditch treatments. The following narrative is a discussion of the ditch profile analysis on road 9704, stations 0+00 to 79+05, constructed in the summer of 1978. This road is a standard 1 road with gravel surfacing. Cut slopes were seeded and hydromulched. The ditches did not receive any special treatment. Therefore, statistical comparisons were not made between standards, treatments, etc.

This discussion addresses the aggradation and degradation processes within the ditches by sampling period and the effects of cut slope height, ditch gradient, road gradient, and travel distance within the ditch, on ditch erosional processes.

METHODS

Field Measurements

The original study plan called for cross-sectioning of the ditches at "break points" with a rill meter. Average end-area calculations would then enable determination of changes in ditch volume between periods of measurements. However, due to manpower and money constraints this approach was not taken.

The adopted procedure included periodic surveying of elevation in the ditch thalweg at ten foot intervals. While this procedure cannot be used to accurately estimate the volumetric change in the ditch, it does provide information on aggradation and degradation in terms of an elevation change.

The elevation of the ditch thalweg was surveyed at ten-foot distance intervals between each relief culvert. The tops of the entrances to the culverts were the starting and ending points for each circuit. Survey circuits were closed and acceptable, if the error of closure was less than 0.03 feet. If irregularities, such as slumped material, were encountered; survey points were taken more frequently.

Surveys of the ditch were made in September 1978, just after road completion; in June 1979, and again in October 1979. The major contribution of flowing water to the ditches during the September 1978 to June 1979 was primarily snowmelt. From June 1979 to October 1979 the ditches would be carrying water infrequently during intense rainfall events.

Data Analysis

The ditch elevation surveys followed the ditch thalweg, consequently there were differences in the distances between two specific culverts from one survey to the next. Differences in distances between culverts were usually within 2% of the measured distance of the first survey. Distances for all survey points in the second and third surveys were adjusted, based on distance between culverts for the survey as compared to the distance for the first survey, using the following equation:

$$CDIST = \frac{TDIST1}{TDIST} \times DIST$$

Where: CDIST = corrected distance, ft.

DIST = measured distance, ft.

TDIST1 = total distance between culverts for the first survey, ft.

TDIST = total measured distance between culverts, ft.

All elevations in a particular survey are based on a given elevation of the top of the first culvert inlet. Thus, any freeze-thaw processes or fill settlement which could alter this elevation, would also affect every elevation measurement. Because of the lack of any intermediate benchmarks, survey bias may accumulate over the 7905 ft. length of the ditch. To correct for any accumulative survey errors, survey points for the second and third survey between any two culverts were corrected using the elevation differences of the two culverts compared to the first survey elevations using the following equation:

$$CELEV = ELEV - \frac{(SELEV - SELEV1) + (STELEV - STELEV1)}{2}$$

Where: CELEV = corrected elevation, ft.

ELEV = measured elevation, ft.

SELEV = measured elevation of start culvert, ft.

SELEV1 = original elevation of start culvert, ft.

STELEV = measured elevation of stop culvert, ft.

STELEV1 = original elevation of stop culvert, ft.

Finally, if there were any elevation measurements made at distances in the first survey that were not obtained in the subsequent surveys, elevations for those distances were determined by linear interpolation between the two adjacent survey points.

Summarization and analysis of ditch elevation data were limited to elevations taken at ten foot increments. This interval was selected to eliminate the measurements made while surveying across slumped material. Inclusion of all surveyed points would disproportionally weight the slumping activity. Additionally, measurements made within catch basins at culvert entrances were deleted from the analysis.

An analysis of variance was performed on the data to investigate the effects of ditch gradient, road centerline gradient, cut slope height, distance from starting culvert, and interaction terms, on ditch elevation changes. Ditch degradation was hypothesized to show an increase with increasing ditch slope, road gradient and distance from the start culvert. Also, deposition of sediments in the ditches was expected to increase as cut slope height increased.

Ditch slope and road gradient were classified into 3% slope classes: class 1 = 0-3%, class 2 = 3-6%, etc. Distance was also defined as a class variable: with class 1 = 0-100 feet, class 2 = 100-200 feet, etc. Cut slopes were categorized by vertical height as follows: category 1 = 0-10 feet, category 2 = 10-20 feet, category 3 = 20-30 feet.

If a class variable significantly affected ditch elevation changes, then a Duncan's multiple range test ($\alpha = 0.05$) was performed on the means for the classes.

RESULTS AND DISCUSSION

Mean ditch elevation differences between surveys were calculated for the entire length of road, the lengths of road in each watershed, and the lengths of road that could contribute to the downslope stream section at each stream crossing (Table 13). Ditch erosion for the first winter and

Table 13. Mean ditch elevation differences between survey dates by watershed and stream crossing.

	Mean Ditch Elevation Change		
Location	Sept. 1978- June 1979	June 1979 Oct. 1979	Sept. 1978- Oct. 1979
	feet		
Watershed 18	+0.06 1/	-0.04	+0.02
Crossing 18-1	+0.06	-0.09	-0.03
Crossing 18-2	+0.01	-0.05	-0.03
Crossing 18-3	-0.07	-0.05	-0.13
Watershed 16	-0.06	-0.01	-0.07
Crossing 16-1	-0.05	-0.06	-0.11
Crossing 16-2	-0.08	+0.06	-0.02
Watershed 15	+0.03	-0.11	-0.08
Road 9704 0 + 00 - 79 + 05	+0.04	-0.05	-0.01

1/ positive values indicate degradation and negative values indicate aggradation.

spring following construction averaged 0.04 feet. During the first summer after construction a deposition of 0.05 ft. occurred in the ditches; thus, the net change one year after road construction was 0.01 feet of deposited material.

Differences in mean elevation measurements give some indication that ditch aggradation and degradation processes have occurred. However, these data do not provide information pertaining to the variability of these processes or how different road parameters affect these processes. In most instances the standard deviation around the mean was equal to or greater than the mean value, indicating a highly variable process.

The results of the analysis of variance tests indicated that road centerline gradient, ditch gradient, distance from the beginning culvert, cut slope height and the interactions of distance * ditch gradient and distance * road centerline gradient were usually highly significant ($\alpha = 0.01$) in explaining the variability in ditch elevation changes. However, the coefficient of determination was very low, usually less than 0.20. Thus, indicating a highly variable process that is only partially explained by the above variables.

Ditch gradient and road centerline gradient are directly correlated; therefore, the analysis of variance tests were made using either variable, but not both. Road centerline gradient which was easily obtainable from the road plan explained as much variance as the ditch gradient; therefore, the results discussed will not include the ditch gradient variable.

Duncan's multiple range tests were made on the means of ditch elevation changes by cut slope height category and by road centerline gradient (Tables 14 & 15). Data from the entire length of road were used for these tests. During spring snowmelt ditch erosion was occurring below categories

Table 14. Mean ditch elevation change by cut slope height category and sampling period. Values above the same line are statistically similar at $\alpha = 0.05$ using Duncan's multiple range test.

	Mean Elevation Change, ft.[1] Cut Slope Height Category[2]			
Sept. 1978- June 1979	0.086 1	0.010 3	0.000 2	-0.030 9
June 1979- Oct. 1979	0.032 9	-0.047 1	-0.052 2	-0.197 3
Sept. 1978- June 1979	0.039 1	0.002 9	-0.052 2	-0.187 3

---

[1] Negative values indicate ditch aggradation and positive values indicate degradation.

[2] Cut slope height category 1 = 0-10 ft., 2 = 10-20 ft., 3 = 20-30 ft., and 9 = no cut slope.

Table 15. Mean ditch elevation change by road centerline gradient and sampling period. Values above the same line are statistically similar at $\alpha = 0.05$ using Duncan's multiple range test.

	Mean Elevation change, ft. [1] Road Centerline Gradient Category [3]		
Sept. 1978- June 1979	0.122 3	0.047 2	-0.017 1
June 1979- Oct. 1979	-0.007 3	-0.039 1	-0.067 2
Sept. 1978- Oct. 1979	0.115 3	-0.020 2	-0.057 1

---

[1] Negative values indicate ditch aggradation and positive values indicate degradation.

[2] Road centerline gradient category 1 = 0-3%, 2 = 3-6%, and 3 = 6-9%.

1 and 3 cut slopes. This erosion was probably caused by the interception of subsurface water from the upslope areas. Typically the ditches have flowing water for 3 to 4 weeks during the snowmelt period. Deposition occurred in the ditch during the summer and early fall. The amount of aggradation which increased with increasing cut slope heights was probably produced by slumping and dry ravelling of the cut slopes.

Ditch degradation increased with increasing road gradient during the first snowmelt period. Ditches along the steeper roads (6-9%) eroded 0.122 feet. The steeper ditches (6-9%) had net degradation after the first year while the ditches with lesser gradient had net aggradation for the same time period.

The interaction between cut slope height category, road gradient and elevation change of the ditch is shown in Figure 12. Ditch degradation only occurs in the steepest gradient category, 6-9%, along those portions of the road with small cut slopes. Aggradation occurs as a result of contributions from the larger cut slopes. Apparently gradients of less than 6% do not allow for sufficient flow velocities to erode the ditch. Erosion occurs in these ditches, but cut slope deposition tends to be slightly greater.

The distance variable was included in the analysis on the assumptions that longer ditches would carry more water and that energy for erosion increases with increasing distance. The effects of this parameter could only be evaluated by selecting road segments with a relatively constant downsloping grade between culverts. In the analysis of variance, both the distance variable and the distance * road gradient variable were highly significant for time periods Sept. 1978 to June 1979 and Sept. 1978 to Oct. 1979. During the summer time period the distance terms were not

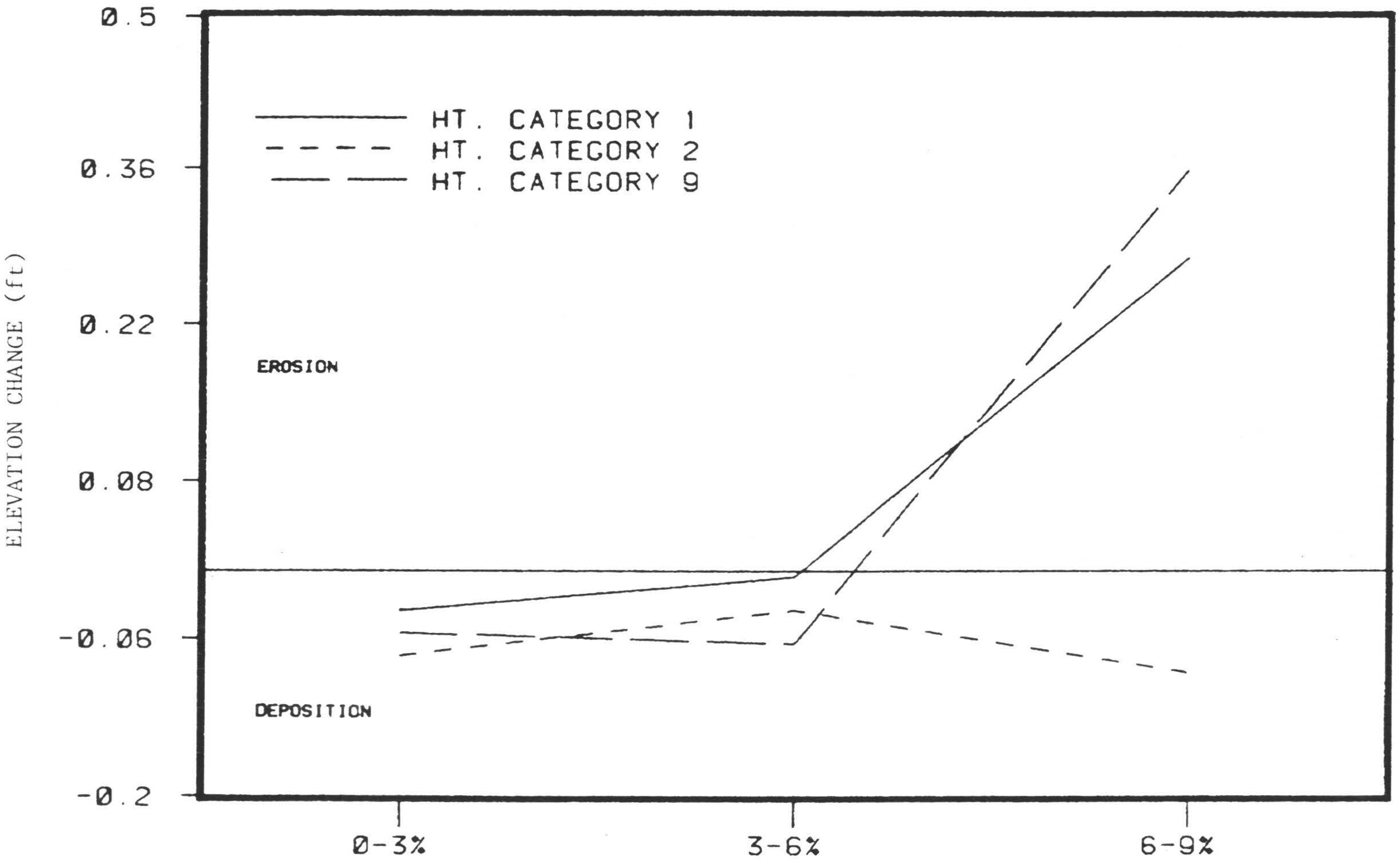


Figure 12. Ditch elevation change as related to cut slope height category and road centerline gradient.

significant. In the summer the ditches seldom carry large volumes of water. This consideration, plus the fact that dry ravelling may be loading the ditches in the summer, indicate that distance is comparatively less important in summer than during snowmelt periods.

Figure 13 shows the relationship between ditch elevation changes and the distance variable. In general, deposition occurs in the first 100 feet of ditch. However, as distance increases, ditch erosion occurs at increasing rates. Data were limited beyond 300 feet; therefore, distances greater than 300 feet were deleted from the analysis.

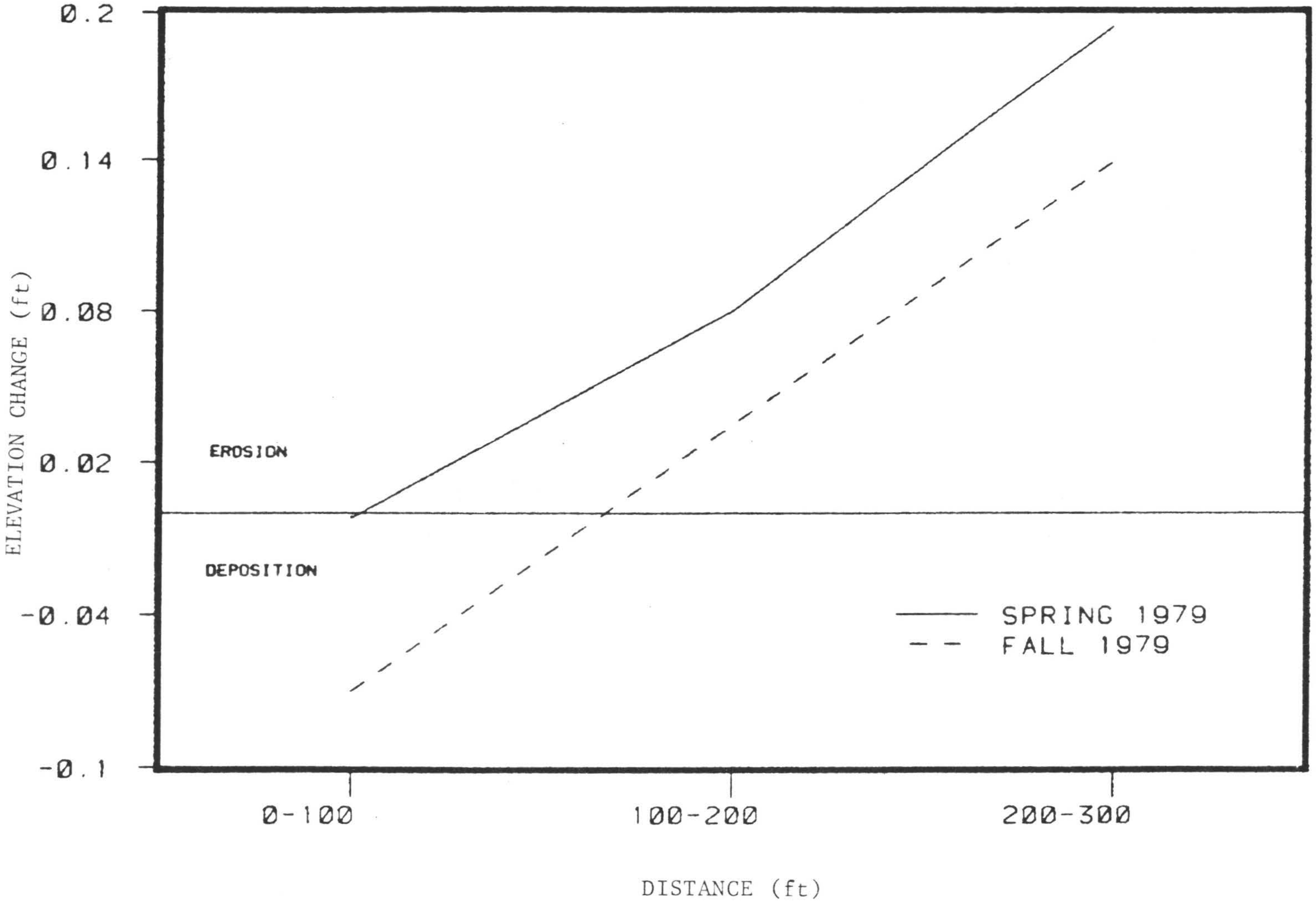


Figure 13. The relationship between ditch elevation changes and distance between culverts.

CHAPTER 8

CALIBRATION OF THE HORSE CREEK WATERSHEDS

INTRODUCTION

Forest Management activities such as road construction and timber harvesting may cause changes in the hydrologic response of a watershed. Modifications of annual water yield, seasonal yields, the timing of snowmelt, streamflow extremes, and storm runoff volumes may occur following site disturbance. The objectives of this portion of the study were to calibrate the ten south facing subwatersheds in the Horse Creek and to determine if the roads constructed in 1978 and 1979 altered the hydrology of the subwatersheds. If the roads do not significantly alter hydrologic characteristics, then the post road data will be included in the calibrations for evaluation of harvesting which is scheduled for 1981 and 1982.

Streamflow records have been maintained on these ten subwatersheds since 1975 and in a few instances include 1974. Roads were constructed in subwatersheds 18, 16, and 8, in 1978. Subwatersheds 14, 12 and 10 were roaded in the summer of 1979. Two design standards of road were constructed with different stabilization and surfacing treatments (Table 16). Typically standard 1 roads disturb 7.6 acres/mile of road and standard 2, 5.1 acres/mile of road.

METHODS

The major change in stream flow expected from the addition of roads to a watershed was an increase in flow volumes. Primarily because of a reduction in stand volume with subsequent decrease in evapotranspiration losses, plus increased transmission rates of water through the watershed.

Table 16. Characteristics of the Horse Creek roads constructed in 1978 and 1979.

Subwatershed	Road Standard	Road Surface	Slope Treatment
18	I	Gravel	Seed and Hydromulch
16	I	Gravel	Seed and Hydromulch
14	II	Asphalt	Seed, Straw Mulch with Asphalt Tack
12	I	Native Soil	None
10	II	Native Soil	Seed (fills only)
8	II	Gravel	Seed, Straw Mulch and Asphalt Tack

Subsurface water intercepted by road cut slopes, is transported through the ditch system as surface flow. Surface waters from road surfaces and ditches often drain directly into stream channels, thus, affecting the normal transmission processes on the watershed. The result of this change is a decrease in transmission losses and more rapid stream flow response. Much of the water moving through the ditch system is discharged below the road onto the forest floor via relief culverts. Therefore, changes in watershed response from the presence of roads is related to the number of live stream crossings and the length of ditch contributing to these crossings.

Flow duration curves were determined for individual subwatersheds for each water year of record using mean daily stream discharge (ft^3/sec). The parameters selected for calibrations were peak flow (QPEAK), julian date of peak flow (PEAKDAY), minimum flow (QMIN), and annual water yield (YIELD). The intermediate stream discharges selected from the flow duration curves were flows which were equalled or exceeded five percent of the time (Q5), 25 percent of the time (Q25) and 75 percent of the time (Q75). The Q5 flows typically represent the 18 days of highest flow which occur during the snowmelt season. The Q25 flows represent the flows during the entire snowmelt season, plus a few summer convective storms and Q75 represents relatively low flows which occur in the late summer and fall. The subwatersheds responses to individual rain events were not evaluated.

Calibration of the roaded watersheds was conducted in the following manner. Simple linear regression techniques were used to develop equations and associated statistics for QPEAK, PEAKDAY, QMIN, Q5, Q25 and Q75 from each subwatershed (dependent variable) as related to the control watershed (independent variable). The regression equations were evaluated for significance at $\alpha = 0.05$. Confidence intervals (95%) were calculated for the significant regressions using the following equation:

$$CL(95\%) = \bar{y} + \hat{\beta}_1(X-\bar{X}) \pm t_{.05}\, S_{y.x}\sqrt{\frac{1}{n} + \frac{(X-\bar{X})^2}{\Sigma X^2}}$$

Where: $CL(95\%)$ = 95% confidence limits

$\bar{y}$ = mean of the observations for the treated watershed

$\hat{\beta}_1$ = the slope regression coefficient

X = the value of the variable for control subwatershed 6

$\bar{X}$ = the mean of the pre-road observations from control subwatershed 6

t = student's t for n-2 degrees of freedom

$S_{y.x}$ = the standard deviation of y for a fixed x

n = the number of pre-road observations

ΣX^2 = the sums of squares of the pre-road observations from control subwatershed 6

The regression equations, confidence limits and pre-road observations were plotted for individual subwatersheds for each variable. Post-road observations were superimposed on the appropriate plot; values falling within the confidence bands indicate that roads did not significantly affect that particular variable. A post-road observation falling outside the confidence intervals was considered as a significant change in the watershed hydrology as reflected in that variable.

RESULTS

The coefficients of determination for the calibration regressions (Table 17) indicate strong relationships between the control and other watersheds for the variables of YIELD, Q5, Q25 and Q75. The variables QPEAK and PEAKDAY are strongly correlated with the control subwatershed for subwatersheds 8, 10, 12 and 14. These four watersheds have mean elevations similar

Table 17. The coefficients of determination for the calibration equations of the Horse Creek subwatersheds, prior to road construction.

Variable	SUBWATERSHED					
	8	10	12	14	16	18
QMIN	0.93	0.29*	0.89	0.51*	0.32*	0.63*
Q75	0.94	0.99	0.96	0.96	0.98	0.91
Q25	0.99	0.99	0.99	0.96	0.87	0.82
Q5	0.96	0.99	0.99	0.99	0.98	0.99
QPEAK	0.97	0.97	0.93	0.95	0.53	0.37
PEAKDAY	0.99	0.99	0.99	0.99	0.37*	0.64*
YIELD	0.98	0.99	0.99	0.99	0.99	0.98

* Regression was not significant at $\alpha = 0.05$.

to the control subwatershed. Subwatersheds 16 and 18 have mean elevations which are approximately 450 feet higher than the control and peak flow usually occurs 2 weeks later in the year. These differences partially explain the low coefficients of determination for the QPEAK and PEAKDAY regression equations. The PEAKDAY regressions for these two subwatersheds were not significant at $\alpha = 0.05$.

High coefficients of determination for QMIN occurred for the regressions on subwatersheds 8 and 12 where stream records indicate several days of approximately the same low stream discharge. Selection of QMIN may be a function of instrument accuracy and precision and not necessarily actual watershed behavior. Consequently, regressions based only on the day of lowest flow are of questionable usefulness.

The regression coefficients and associated statistics for each calibration are presented in Appendix 3.

The plots of pre-road calibrations with post-road observations (Appendix 4) indicate only a few significant differences due to the presence of roads. As expected, the effects of Horse Creek roads on watershed hydrologic behavior were minimal; primarily because a small percentage of the subwatersheds (1.9 to 4.1%) was disturbed by roads (Table 18). Significant changes in hydrologic behavior, attributable to roads, were not identified for subwatersheds 8, 14 and 16. Also, roads did not significantly alter QPEAK, PEAKDAY and QMIN for all of the drainages tested.

Increases in YIELD, Q25 and Q5 occurred in subwatershed 12. This subwatershed had 3.9 percent of its area disturbed by roads. The road is located at mid-slope where it can potentially intercept subsurface flow from a relatively large upslope area. The resulting increases above the predicted values were 9.5% for high flows (Q5) during the peak period of

Table 18. Road information for the ten south facing Horse Creek subwatersheds.

Subwatershed	Road Standard	Road Length (mi.)	Area in Roads (%)[1/]	Number of Stream Crossings	Relief Ratio (ft/ft)
18	I	1.147	4.1	3	0.17
16	I	0.278	3.0	2	0.18
14	II	0.567	1.9	4	0.23
12	I	1.055	3.9	3	0.22
10	II	0.860	2.7	2	0.25
8	II	2.606	3.7	3	0.22

[1/] Standard I and II roads disturb 7.6 and 5.1 acres per mile of road, respectively.

the snowmelt hydrograph; 32.0% for the snowmelt period (Q25); and 16.3% for the water year 1980 (YIELD).

Snowmelt flows (Q25) and the 75% exceedance flows increased by 14.6% and 15.7%, respectively, on subwatershed 10. Annual water yield did not increase for this watershed, therefore these differences reflect a change in watershed response to hydrologic events with subsequent change in the shape of the flow duration curve. Subwatershed 10 contained a midslope road capable of intercepting subsurface flow from a large upslope contributing area. Also, a relief culvert in the watershed contributes water to the stream from a seep in the cut slope. Transmission losses are probably decreased and transmission rates increased as a result of the road.

Subwatershed 18, with 4.1 percent of its area in roads, exhibited a decrease in the 5% exceedance stream flows; the 18 days of highest stream flow during snowmelt. The decreases were very large, 48.8 and 54.4% for the water years 1979 and 1980, respectively. The road in this subwatershed is in the upper one-fourth of the drainage; thus, subsurface flow interception by the road is much less than in subwatersheds 10 and 12. Also 0.2 miles of the road is on the ridge between two subwatersheds and minimal subsurface runoff is intercepted in this section. The decreases in the Q5 flows reflect a narrowing of the snowmelt hydrograph without a change in peak flows. In subwatershed 8 with a road density (3.7%) and location (upper portion) similar to subwatershed 18, no significant changes in hydrologic response occurred. Apparently road location in some circumstances such as in drainages 10, 12 and 18 can have significant effect on stream flow behavior; whereas with subwatershed 8 no detectable changes were observed.

CHAPTER 9

SUMMARY AND CONCLUSIONS

CUT AND FILL SLOPE EROSION

Sheet and rill wash, dry raveling and slumping appeared to be the dominant processes by which sediments were detached and transported from cut and fill slopes located on the Horse Creek road sections investigated in this study.

Sheet and rill erosion processes were dominant on fill slopes particularly during and immediately following summer rainfall events; some slumping was observed on these slopes during spring snowmelt. The high intensity, short duration convective storms associated with the summer season produced accelerated erosion conditions on newly constructed unprotected fill slopes.

Slumping of material with subsequent downslope transport during spring snowmelt was the major contributor to cut slope erosion. Dry raveling during summer months contributed to some cut bank erosion with surface and rill wash on these slopes being the least important.

Erosion was greater on fill slopes compared to cut banks the first summer after construction. However, with subsequent summers, cut slope sediment yields approached or exceeded fill slope erosion. For example, first summer fill slope erosion on road 9704, stations 0+00 to 79+05, treatment 1, was estimated to be 0.54 ft^3/trap where as cut slope erosion for that period was essentially zero. Fill and cut slope yields for this section of road after the third summer of data collection were 1.00 ft^3, and 1.39 ft^3/trap, respectively. Winter erosion was comparatively greater on cut slopes.

Erosion tends to increase with slope height on cut and fill slopes.

Accumulated erosion on cut slopes with height classes 2, 3 and 4 exceeded yields from class 1 slopes by factors of 5.5, 7.5 and 10.0, respectively. Height classes 2, 3 and 4 on fill slopes produced respective yields of 7.7, 17.5 and 19.5 times greater than class 1 slopes for the same road section.

The fill slopes began to stabilize after the first summer. Sediment yields from these areas declined steadily with time. Cut bank erosion did not follow this trend. Second winter erosion on cut slopes was greater than first winter yields. Apparently cut bank stabilization on these roads takes longer than the time period covered in this analysis. Subsequent years of data analysis will most likely provide more insight into the degree and time span of cut slope stabilization.

Surface stabilization efforts resulted in reduced erosion on the cut and fill areas. For example, erosion from a class 1, fill slope on road 9704 which had been treated with hydroseed and mulch was 53% less after the second summer than a nontreated class 1 slope. A large reduction in loose soil transported from the toe of fill slopes was obtained by addition of filter windrows at the toe. Class 1 fill slopes unprotected by windrows produced 1280% more transported sediments than similar class 1 windrow protected slopes. The difference was greater on class 2 slopes (6920%) unprotected areas.

CUT AND FILL SLOPE MODELING

Prediction equations were developed to estimate accumulated fill and cut slope erosion as a function of time or precipitation. The regression model selected for use was of the form; $Y = \beta_0 + \beta_1 X + \beta_2 \ell n X + \varepsilon$. The equations for fill slope erosion appear to represent observed erosion trends. However, only two years of record and a limited number of road segment data were used. Therefore, caution is suggested on the interpretation of results obtained from extrapolation of time periods and application to other roads. Additional data with subsequent refining of these equations are needed before application can be recommended.

Regression techniques were applied to cut slope data. However, a poor "lack of fit" led to abandonment of development of predictive equations. Perhaps additional periods of record will permit development of representative predictive equations for cut slope erosion on the Horse Creek roads.

Equations were also developed for predicting the rate of fill slope erosion as a function of time since trough installation. The regression model used was of the form: $\ell n\, Y = \beta_o + \beta_1\, \ell n X + \varepsilon$. Similar caution is requested in the use of these equations.

Comparison of the Horse Creek fill slope of erosion rate model with the Bogus Basin fill slope erosion rate model (Megahan, 1974), for a 704 day period on a Horse Creek road, revealed that the equation developed for the Bogus Basin predicts 42% less fill slope erosion than the Horse Creek model developed in this study.

RILL AND GULLY EROSION

Rill surveys were conducted on the entire length of road to estimate fill slope erosion volumes. For two years after road construction fill erosion amounted to approximately 29,000 tons/mi^2 with approximately 44 percent occurring the first summer, before fills were hydromulched.

The rill survey erosion estimates were considerably less than (approximately 45%) the estimates from the fill traps. This difference is partially caused by the lack of erosion volumes from slumps and the omittance of sheet erosion or raindrop splash erosion volumes in rill survey data.

The transport distance of fill material below rills was quite variable. In those situations where road runoff was diverted to the fills, large rills developed which transported material downslope great distances. Once these drainage patterns were established, fill slope height and the slope of the forest floor determined subsequent downslope transport. On the average, approximately 73% of the eroded fill material is deposited on the forest floor within 50 feet of the toe of the fill.

The use of filter windrows to prevent fill material from leaving the slope was very effective for the two years following construction. The average transport distance below windrows was less than four feet. Typically, material did not move readily through the windrows. During the spring when snow cover was present on the windrows, eroded material was transported over the snow covered windrows. The establishment of windrows appear to be an effective method for protecting streams from contributions of sediment from fill slopes.

DITCH EROSION

Ditch elevation changes for the first year after construction of road 9704 were highly variable. Typically, degradation of the ditch occurred during snowmelt with aggradation occurring during the summer. The mean change over the first year was an increase in elevation of 0.01 feet, indicating net deposition.

The variables of road gradient and distance of travel were significantly positively correlated with ditch degradation. Cut slope height was significantly and positively correlated with aggradation. On-site measurements of cut slope erosion have shown a direct relationship between the volume of material delivered to the ditch and slope height.

Ditch erosion for road 9704 increased rapidly as slope increased above approximately 6%; if cut slopes were less than 10 feet high. Cut slopes with heights greater than 10 feet deposited more material in the ditch than that lost to ditch degradation.

During the winter and spring when ditch degradation was occurring, cut slope erosion amounted to 2768 ft^3 for the entire road. Ditch degradation during this same period was 0.04 ft. Assuming the degradation occurred over a 6 inch width, this would equate to 148 ft^3 for the road. In comparison, ditch erosion during snowmelt is approximately 5% of cut slope erosion.

FLOW DURATION AND ROADS

Increases in snowmelt flows (Q25) were exhibited in subwatersheds 10 and 12 where roads had comparatively large contributing areas of surface flow. Roads located in the upper portion of a drainage either produced no change in flow characteristics (subwatershed 8) or caused a decrease in the 5% exceedance flows (subwatershed 18). Peakflow and timing of peakflow remained unchanged by the introduction of roads on all of the subwatersheds tested. Significant changes in annual stream yields were detected only in subwatershed 12.

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APPENDIX

APPENDIX 1

Average fill slope erosion (ft³/trough) and associated statistics

	Station 0+00 to 79+05 Road type[1] A				Station 0+00 to 79+05 Road type B				Station 79+05 to 129+37 Road type C				Station 129+37 to 194+00 Road type D				Station 194+00 to 238+70 Road type E			
	Height[2] class	n	$\bar{x}$	S^2	Height[2] class	n	$\bar{x}$	S^2	Height[2] class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2
Cumulative erosion 8-17-78 to 7-19-80	1	5	1.38	5.28	1	5	0.10	5.70	1	6	0.39	10.0	1	10	0.66	0.417	1	1	0.230	–
	2	3	3.51	8.11	2	9	0.05	0.60	2	4	1.40	29.3	2	4	2.69	4.688	2	3	0.990	0.869
	3	1	2.01	–	3	0	–	–	3	1	8.46	–	3	3	3.00	2.666	3	4	1.690	3.098
													4	2	6.00	11.472	4	3	2.430	0.863
First summer	1	5	1.14 (0.248)[3]	4.98 (0.236)	1	5	0.000	0.000	1	6	0.29 (0.075)	8.0 (0.55)	1	10	0.060 (0.050)	0.005 (0.004)	1	1	0.100 (0.087)	–
	2	3	1.82 (0.396)	1.67 (0.079)	2	9	0.004	0.050	2	4	0.58 (0.173)	14.0 (0.99)	2	4	0.092 (0.080)	0.013 (0.010)	2	3	0.048 (0.041)	0.010 (0.008)
	3	1	0.54	–	3	0	–	–	3	1	3.01 (0.792)	–	3	3	0.003 (0.0031)	0.03 x 10^{-3} (0.03 x 10^{-3})	3	4	0.003 (0.002)	0.25 x 10^{-4} (0.02 x 10^{-3})
													4	2	2.005 (1.744)	7.960 (6.017)	4	3	0.025 (0.018)	0.07 x 10^{-2} (0.54 x 10^{-3})
First	1	5	0.01	0.0005	1	5	0.004	0.030	1	6	0.05 (0.003)	0.10 (0.0002)	1	10	0.221 (0.038)	0.038 (0.04 x 10^{-3})	1	1	0.050 (0.002)	–
	2	3	0.24	0.1600	2	9	0.008	0.027	2	4	0.50 (0.019)	87.0 (0.128)	2	4	0.880 (0.802)	0.802 (0.001)	2	3	0.400 (0.014)	0.156 (0.0002)
	3	1	0.05	–	3	0	–	–	3	1	3.25 (0.125)	–	3	3	0.850 (0.152)	0.152 (0.02 x 10^{-2})	3	4	1.020 (0.037)	1.028 (0.0013)
													4	2	1.200 (0.020)	0.020 (0.02 x 10^{-3})	4	3	1.130 (0.040)	0.023 (0.03 x 10[illegible])
Second summer	1	5	0.18	0.07	1	5	0.006	0.080	1	6	0.05 (0.004)	1.0 (0.003)	1	10	0.380 (0.210)	0.210 (0.0014)	1	1	0.080 (0.006)	–
	2	3	0.69	0.33	2	9	0.009	0.060	2	4	0.32 (0.026)	35.0 (0.230)	2	4	1.720 (1.594)	1.594 (0.0104)	2	3	0.530 (0.042)	0.199 (0.0013)
	3	1	0.55	–	3	0	–	–	3	1	2.20 (0.178)	–	3	3	2.140 (1.561)	1.561 (0.1015)	3	4	0.660 (0.054)	0.555 (0.0036)
													4	2	2.800 (0.180)	0.180 (0.0011)	4	3	1.270 (0.103)	0.773 (0.0051)
Second winter	1	5	0.11	0.0500	1	5	0.010	0.00			ND[4]				ND				ND	
	2	3	0.02	0.0001	2	9	0.010	0.00												
	3	1	0.40	–	3	0	–	–												
Third summer	1	5	0.15	0.079	1	5	0.076	17.10			ND				ND				ND	
	2	3	0.59	0.134	2	9	0.017	0.05												
	3	1	1.00	–	3	0	–	–												

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[1] Road type A = rock with oil pavement, treatment 1 (hydroseed with mulch).
Road type B = rock with oil pavement, treatment 1 (hydroseed with mulch, windrow protected traps).
Road type C = asphalt road surface, treatment 4 (hydroseed with straw asphalt tack).
Road type D = native material with oil road surface, treatment 4 (control).
Road type E = native material with oil surface, treatment 3 (hydroseed only).

[2] Height class 4 not included.

[3] Data also unitized by ft³/trough/inch precipitation for the period.

[4] ND = no data available at time of analysis.

APPENDIX 2

Average cut slope erosion (ft^3/trough) and associated statistics

	Station 0+00 to 79+05 Road type[1] A				Station 79.05 to 129+37 Road type C				Station 129+37 to 185+10 Road type D				Station 185+10 to 238+70 Road type E				Station 129+37 to 238+70 Summary of road type D&E			
	Height class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2	Height class	n	$\bar{x}$	S^2
Cumulative erosion	1	4	0.81	0.94	1	4	0.16	0.04	1	1	0.91	–	1	5	0.54	0.039	1	6	0.60	0.0543
	2	4	6.96	52.79	2	4	2.23	5.43	2	3	3.19	2.573	2	2	0.44	0.0005	2	5	2.042	3.7512
	3	1	5.81	–	3	0	–	–	3	7	9.66	30.079	3	1	3.45	–	3	8	8.330	29.7391
	4	0	–	–	4	0	–	–	4	2	10.48	0.162	4	0	–	–	4	2	10.48	0.162
First	1	4	0	0	1	4	0.03 (0.0031)[2]	0.002 (0.04 x 10^{-3})	1	1	0.01 (0.003)	–	1	5	0.07 (0.024)	0.003 (0.0003)	1	6	0.063 (0.0201)	0.315 x 10^{-2} (0.032 x 10^{-2})
	2	4	0.04	0.01	2	4	0.07 (0.0089)	0.01 (0.08 x 10^{-3})	2	3	0.13 (0.142)	0.49 (0.005)	2	2	0.05 (0.016)	0.0018 (0.0002)	2	5	0.10 (0.032)	0.2725 x 10^{-1} (0.276 x 10^{-2})
	3	1	0	–	3	0	–	–	3	7	0.61 (0.309)	0.774 (0.142)	3	1	0.27 (0.086)	–	3	8	0.568 (0.180)	0.67742 (0.6858 x 10^{-1})
	4	0	–	–	4	0	–	–	4	2	0.94 (0.298)	1.428 (0.145)	4	0	–	–	4	2	0.94 (0.298)	1.428 (0.145)
First winter	1	4	0.14	0.02	1	4	0.09 (0.0031)	0.01 (0.02 x 10^{-3})	1	1	0.89	–	1	5	0.41 (0.014)	0.011 (0.01 x 10^{-3})	1	6	0.487 (0.017)	0.4819 x 10^{-1} (0.05 x 10^{-3})
	2	4	1.75	3.09	2	4	1.36 (0.0486)	2.02 (0.255 x 10^{-2})	2	3	2.30	1.855	2	2	0.32 (0.012)	0.0001 (0.07 x 10^{-5})	2	5	1.512 (0.05)	2.10177 (0.273 x 10^{-2})
	3	1	0.28	–	3	0	–	–	3	7	5.78	29.101	3	1	2.64 (0.094)	–	3	8	5.388 (0.190)	26.17594 (0.2671 x 10^{-1})
	4	0	–	–	4	0	–	–	4	2	4.72	14.742	4	0	–	–	4	2	4.72 (0.188)	14.742 (0.1217 x 10^{-1})
Second summer	1	4	0.01	0.07 x 10^{-3}	1	4	0.04 (0.005)	0.01 (0.05 x 10^{-3})	1	1	0.01 (0.001)	–	1	5	0.06 (0.006)	0.0074 (0.0001)	1	6	0.048 (0.005)	0.63 x 10^{-2} (0.063 x 10^{-3})
	2	4	1.22	2.32	2	4	0.61 (0.080)	0.39 (0.701 x 10^{-2})	2	3	0.75 (0.075)	0.679 (0.007)	2	2	0.06 (0.006)	0.0002 (0.2 x 10^{-3})	2	5	0.474 (0.047)	0.48253 (0.4825 x 10^{-2})
	3	1	1.39	–	3	0	–	–	3	7	2.669 (0.267)	2.599 (0.026)	3	1	0.54 (0.054)	–	3	8	2.41 (0.241)	2.7958 0.2796 x 10^{-1}
	4	0	–	–	4	0	–	–	4	2	4.805 (0.480)	5.024 (0.050)	4	0	–	–	4	2	4.805 (0.480)	5.024 (0.5024 x 10^{-1})
Second winter	1	4	0.37	0.02	ND[3]				ND				ND				ND			
	2	4	3.34	3.09																
	3	1	0.28	–																
	4	0	–	–																
Third summer	1	4	0.01	0.19	ND				ND				ND				ND			
	2	4	1.22	24.00																
	3	1	1.39	–																
	4	0	–	–																

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[1] Road type - same as Appendix 1.
[2] Data also unitized by ft^3/trough/inch precipitation for the period.
[3] ND = no data available at time of analysis.

APPENDIX 3

Regression Coefficients and Other Statistical Information for the Calibration of the Roaded Horse Creek Subwatersheds

Appendix 3

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on the julian date of maximum stream discharge (PEAKDAY).

Subwatershed	N	$\overline{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\overline{X}^1$	S^2	$SS_X^{\ 3}$
8	4	122.75	-1.572	1.015	122.50	0.385	2050.9
10	5	123.20	0.080	1.001	123.00	0.516	2055.9
12	5	123.40	-0.916	1.011	123.00	0.567	2056.0
14	5	123.20	-1.595	1.015	123.50	0.348	2056.0
16*	5	141.20	88.942	0.423	123.60	14.374	2075.2
18*	5	145.40	53.570	0.743	123.60	14.488	2075.0

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on maximum stream discharge, ft^3/sec (QPEAK).

Subwatershed	N	$\overline{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\overline{X}^1$	S^2	$SS_X^{\ 3}$
8	4	6.178	-0.303	1.352	4.793	0.551	11.787
10	5	3.144	-0.607	0.810	4.632	0.267	12.303
12	5	4.128	-1.962	1.315	4.632	0.712	12.303
14	5	3.360	-1.172	0.978	4.632	0.447	12.302
16	5	1.344	-0.052	0.298	4.687	0.564	12.001
18	5	3.874	1.125	0.586	4.688	1.532	12.007

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on the stream discharge, ft^3/sec, equalled or exceeded five percent of the time (Q5).

Subwatershed	N	$\overline{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\overline{X}^1$	S^2	$SS_X^{\ 3}$
8	4	3.210	-0.118	1.508	2.206	0.400	3.741
10	5	1.456	0.061	0.657	2.126	0.070	3.871
12	5	1.953	-0.046	0.940	2.126	0.042	3.871
14	5	1.713	0.149	0.736	2.126	0.075	3.871
16	4	0.745	0.000	0.338	2.206	0.064	3.740
18	4	2.647	0.214	1.103	2.206	0.013	3.741

[1] Independent variable observations are from the control subwatershed 6.

[2] S = standard deviation of Y holding X constant

[3] SS_X = sums of squares of $(X-\overline{X})$

* = Not significant at α =.05.

Appendix 3 (cont.)

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on the stream discharge, ft^3/sec, equalled or exceeded 25 percent of the time (Q25).

Subwatershed	N	$\bar{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\bar{X}$[1]	S[2]	SS_X[3]
8	4	0.868	0.075	1.435	0.553	0.050	0.314
10	5	0.309	0.013	0.581	0.509	0.012	0.353
12	5	0.423	0.000	0.831	0.509	0.031	0.353
14	5	0.322	-0.049	0.729	0.509	0.051	0.353
16	4	0.155	0.010	0.262	0.552	0.041	0.314
18 *	4	0.735	0.362	0.674	0.553	0.125	0.314

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on the stream discharge, ft^3/sec, equalled or exceeded 75 percent of the time (Q75).

Subwatershed	N	$\bar{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\bar{X}$[1]	S[2]	SS_X[3]
8	4	0.340	-0.029	1.641	0.225	0.042	0.022
10	5	0.106	-0.015	0.586	0.207	0.004	0.028
12	5	0.172	-0.012	0.885	0.207	0.016	0.028
14	5	0.092	-0.057	0.719	0.207	0.013	0.028
16	4	0.042	-0.021	0.278	0.225	0.009	0.022
18	4	0.317	-0.015	1.338	0.225	0.045	0.022

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on minimum stream discharge, ft^3/sec, (QMIN).

Subwatershed	N	$\bar{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\bar{X}$[1]	S[2]	SS_X[3]
8	4	0.194	-0.052	2.115	0.116	0.015	0.002
10 *	5	0.052	0.011	0.371	0.112	0.015	0.002
12	5	0.104	0.024	0.714	0.112	0.006	0.002
14 *	5	0.040	-0.007	0.421	0.112	0.010	0.002
16 *	4	0.022	-0.012	0.290	0.116	0.012	0.001
18 *	4	0.245	-0.103	2.987	0.116	0.061	0.002

[1] Independent variable observations are from the control subwatershed 6.

[2] S = standard deviation of Y holding X constant

[3] SS_X = sums of squares of $(X-\bar{X})$

* = Not significant at $\alpha = .05$.

Appendix 3 (cont.)

Regression coefficients and statistical information for the calibration of the Horse Creek subwatersheds based on annual water yield, the sum of cfs-days (YIELD).

Subwatershed	N	$\bar{Y}$	$\hat{\beta}_0$	$\hat{\beta}_1$	$\bar{X}$[1]	S[2]	SS_x[3]
8	4	317.34	1.579	1.454	217.18	18.786	23417.1
10	5	127.30	-5.186	0.656	202.05	3.572	27997.9
12	5	172.91	-10.615	0.908	202.03	6.754	28001.8
14	5	133.82	-12.578	0.725	202.04	5.400	28003.9
16	4	57.03	-3.782	0.280	217.18	0.529	23419.4
18	4	266.34	31.849	1.080	217.18	15.205	23417.2

[1] Independent variable observations are from the control subwatershed 6.

[2] S = standard deviation of Y holding X constant.

[3] SS_x = sums of squares of $(X-\bar{X})$.

APPENDIX 4

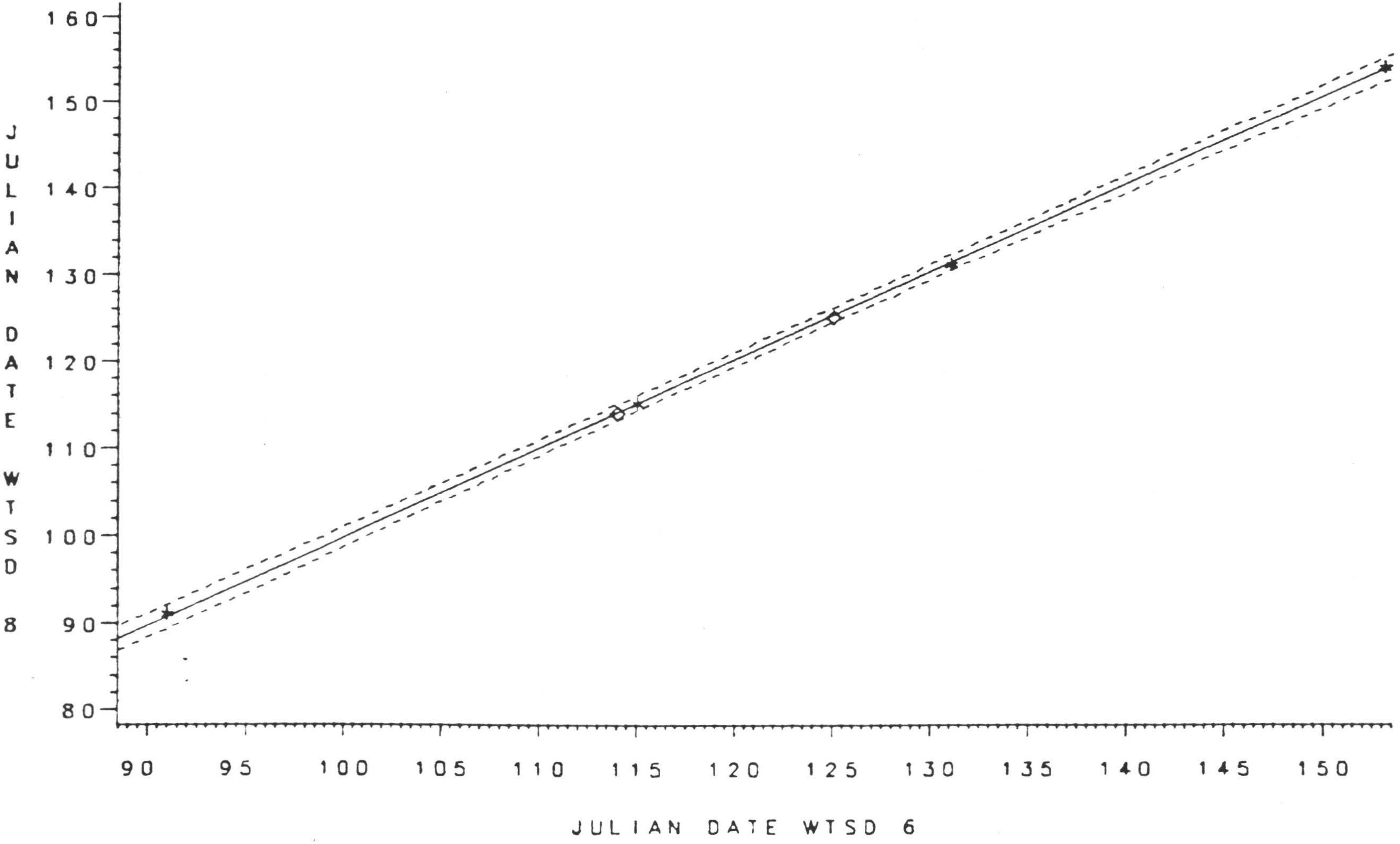
The Pre-road Horse Creek Subwatershed Calibration Equations, 95% Confidence Limits, and Observed Values

* = Pre-road Observations

◊ = Post-road Observations

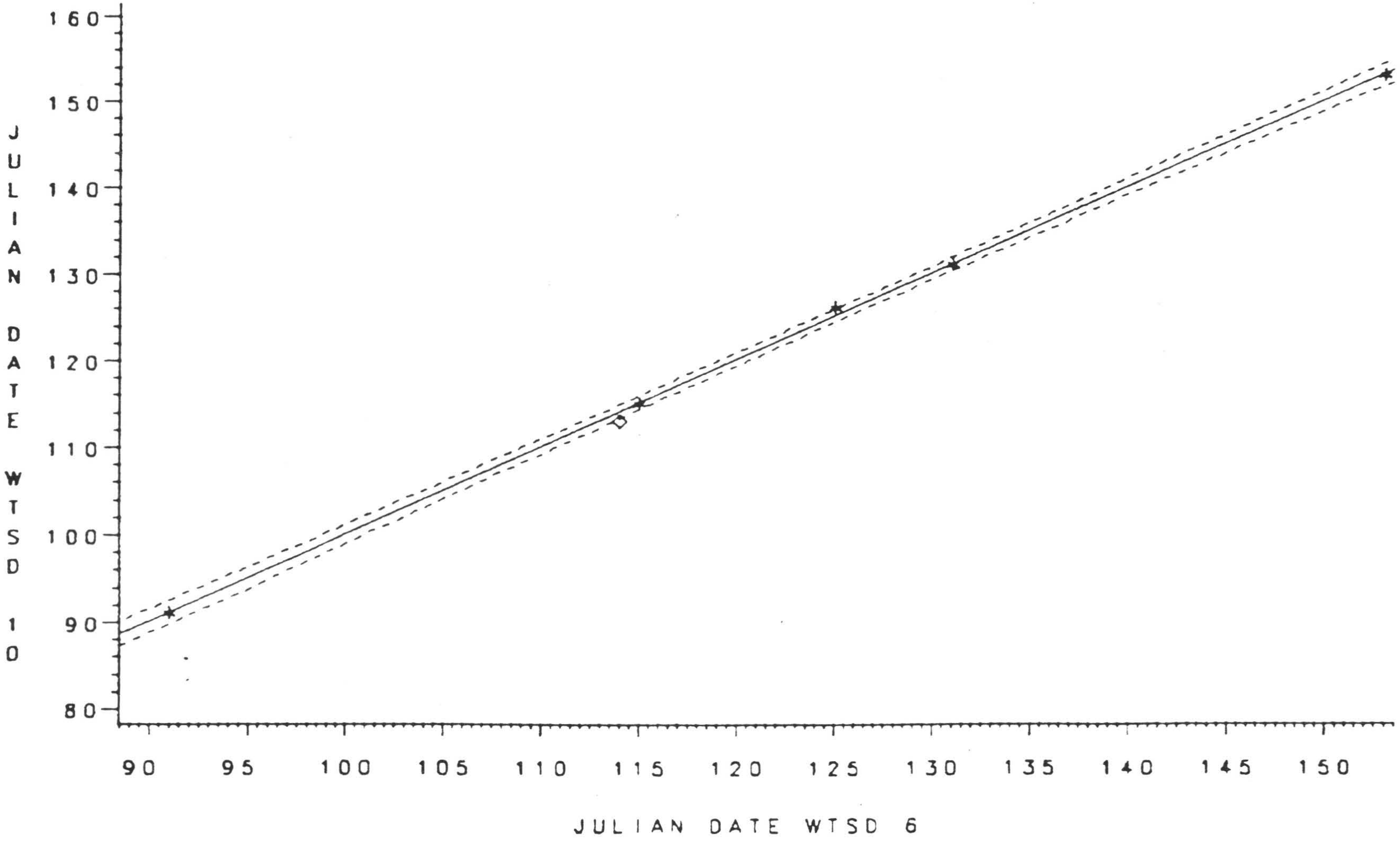
CALIBRATION--WATERSHED 8

JULIAN DATE OF PEAK



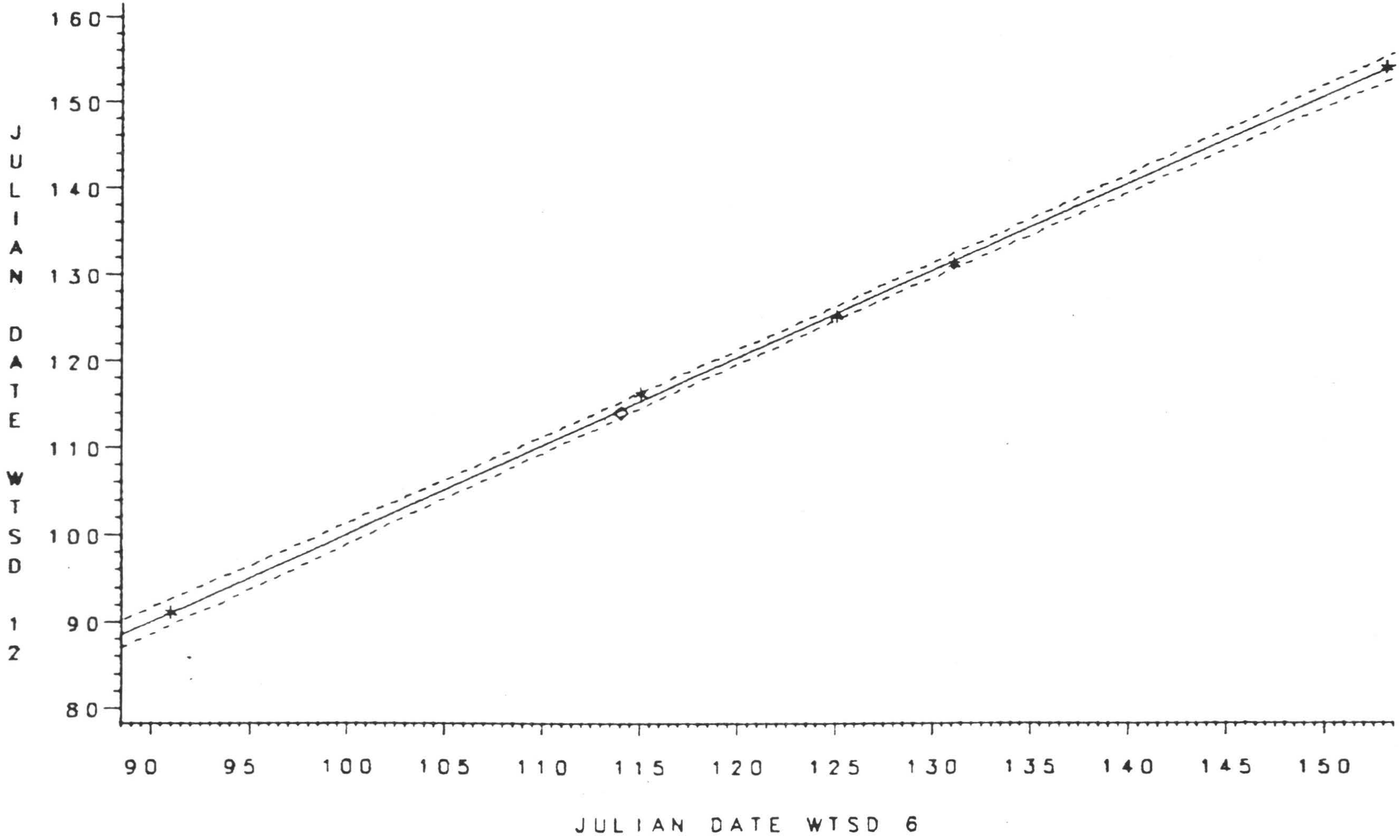
CALIBRATION--WATERSHED 10

JULIAN DATE OF PEAK



CALIBRATION--WATERSHED 12

JULIAN DATE OF PEAK



CALIBRATION--WATERSHED 14

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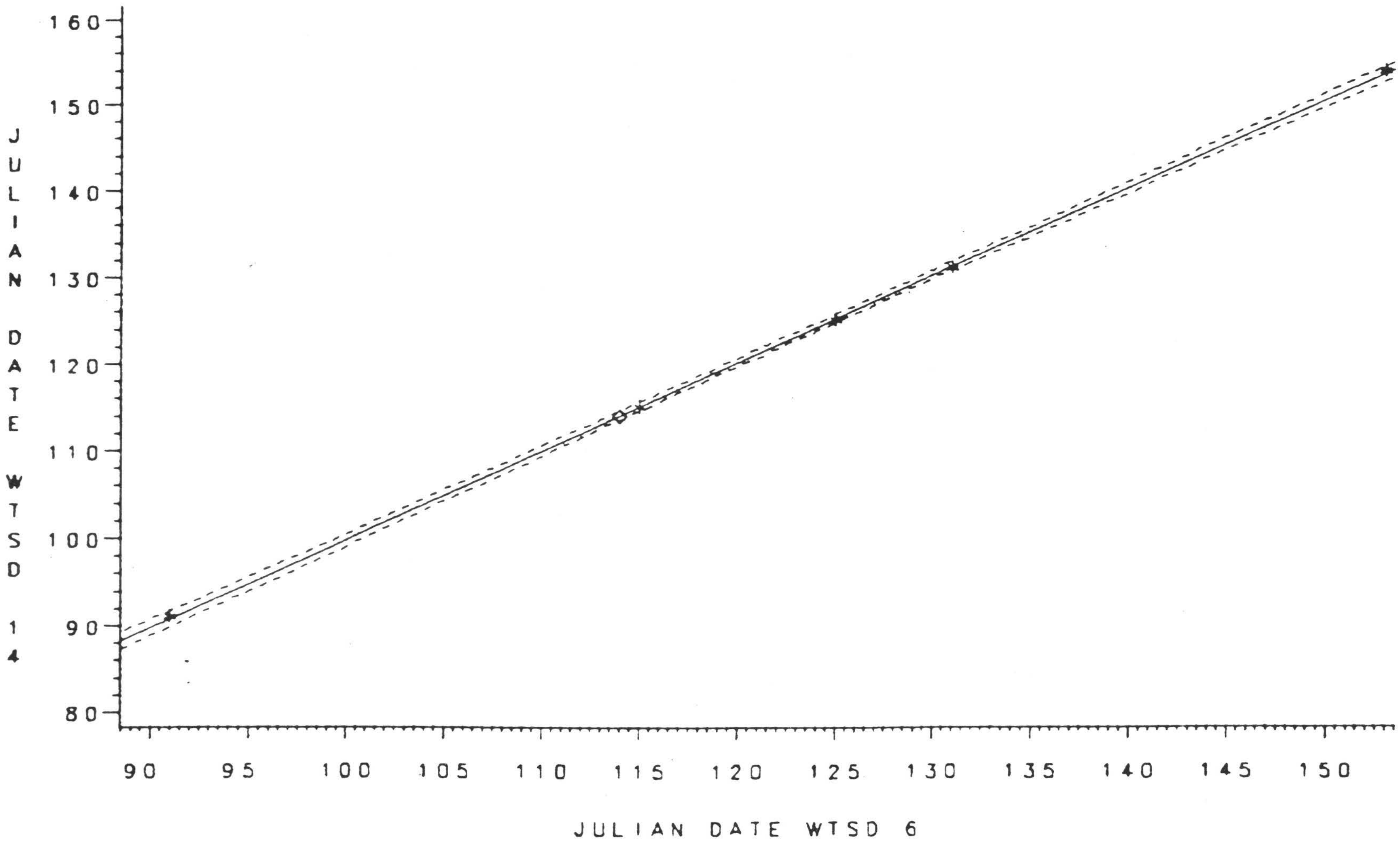
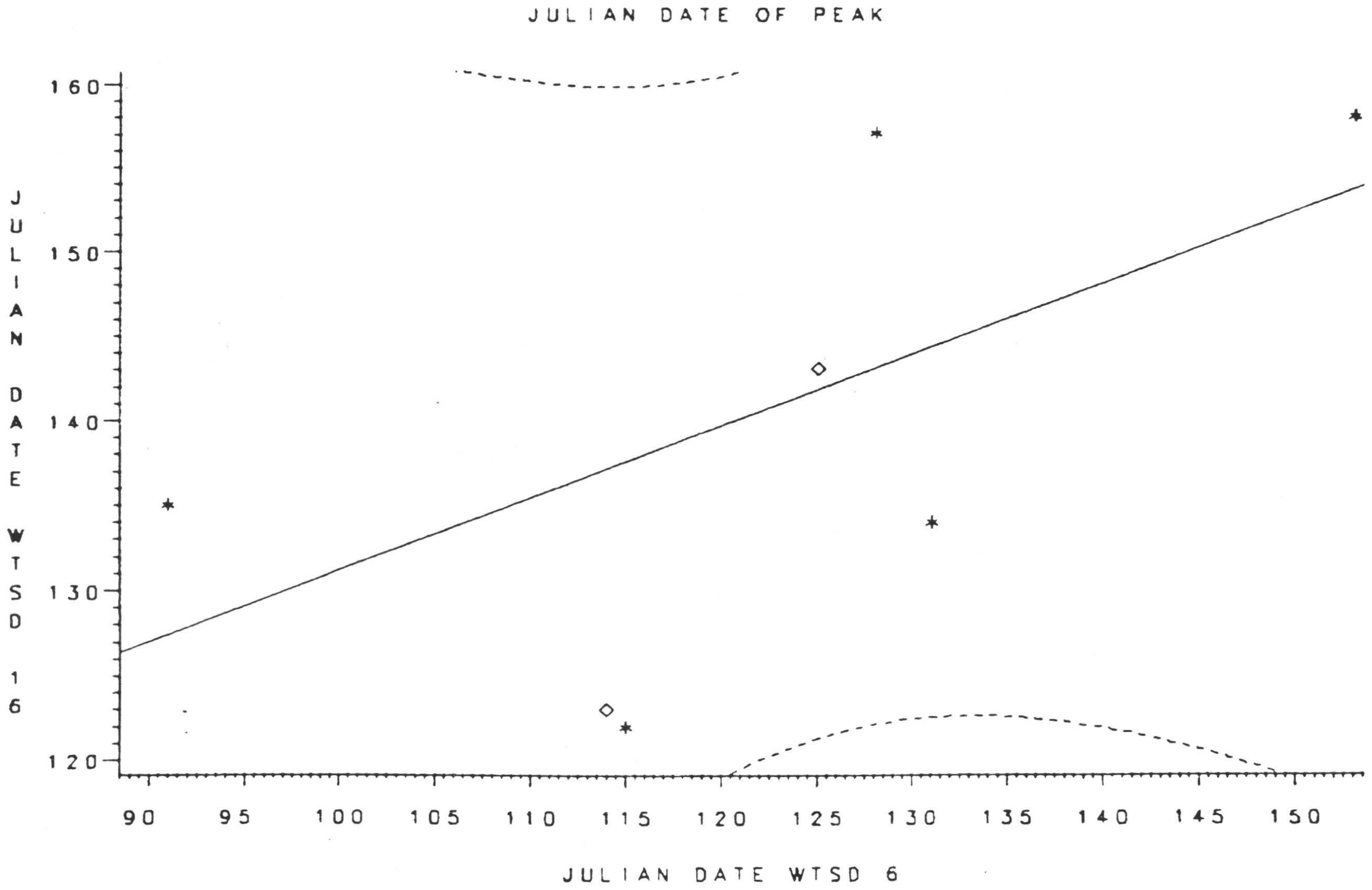
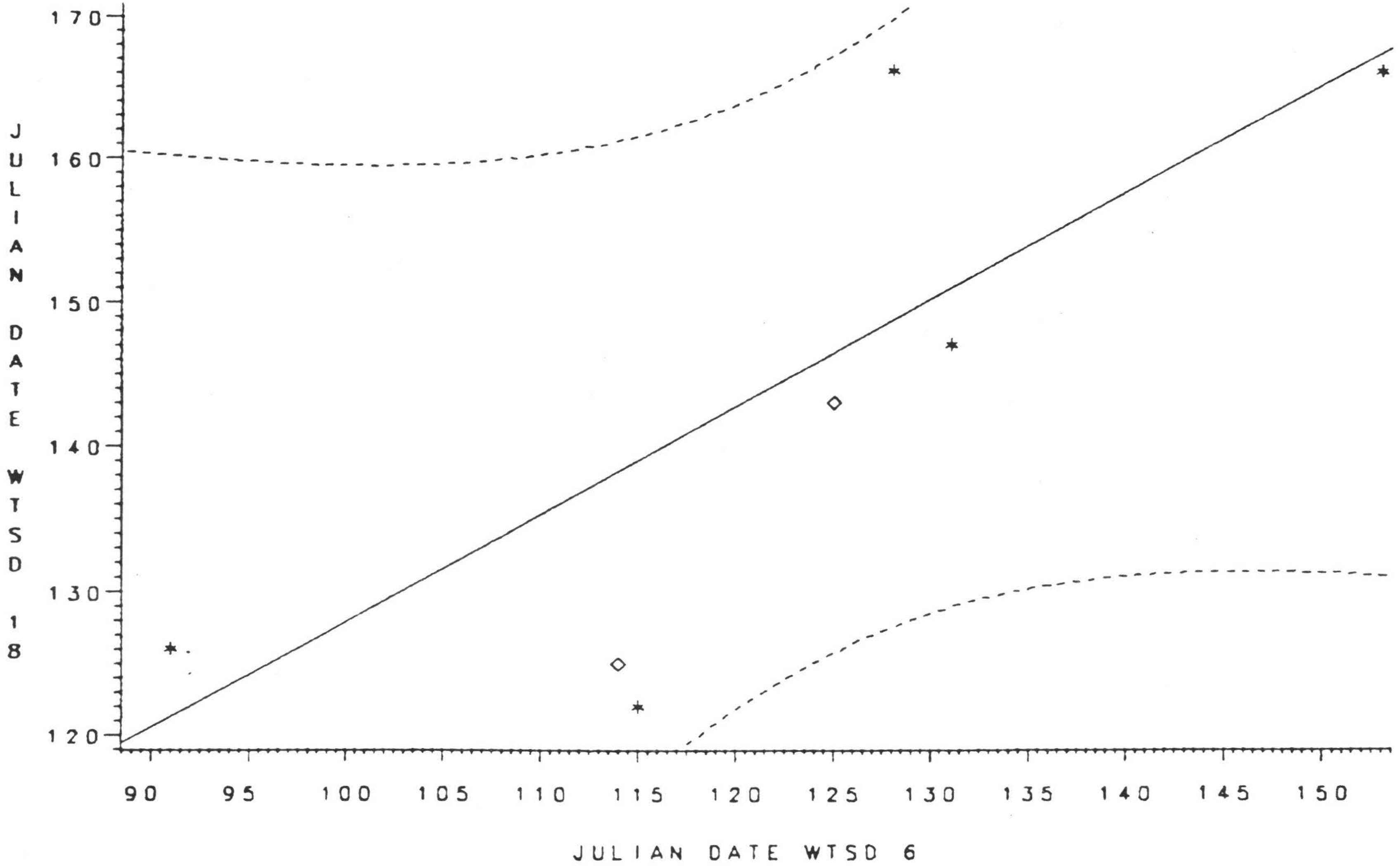


CALIBRATION--WATERSHED 16



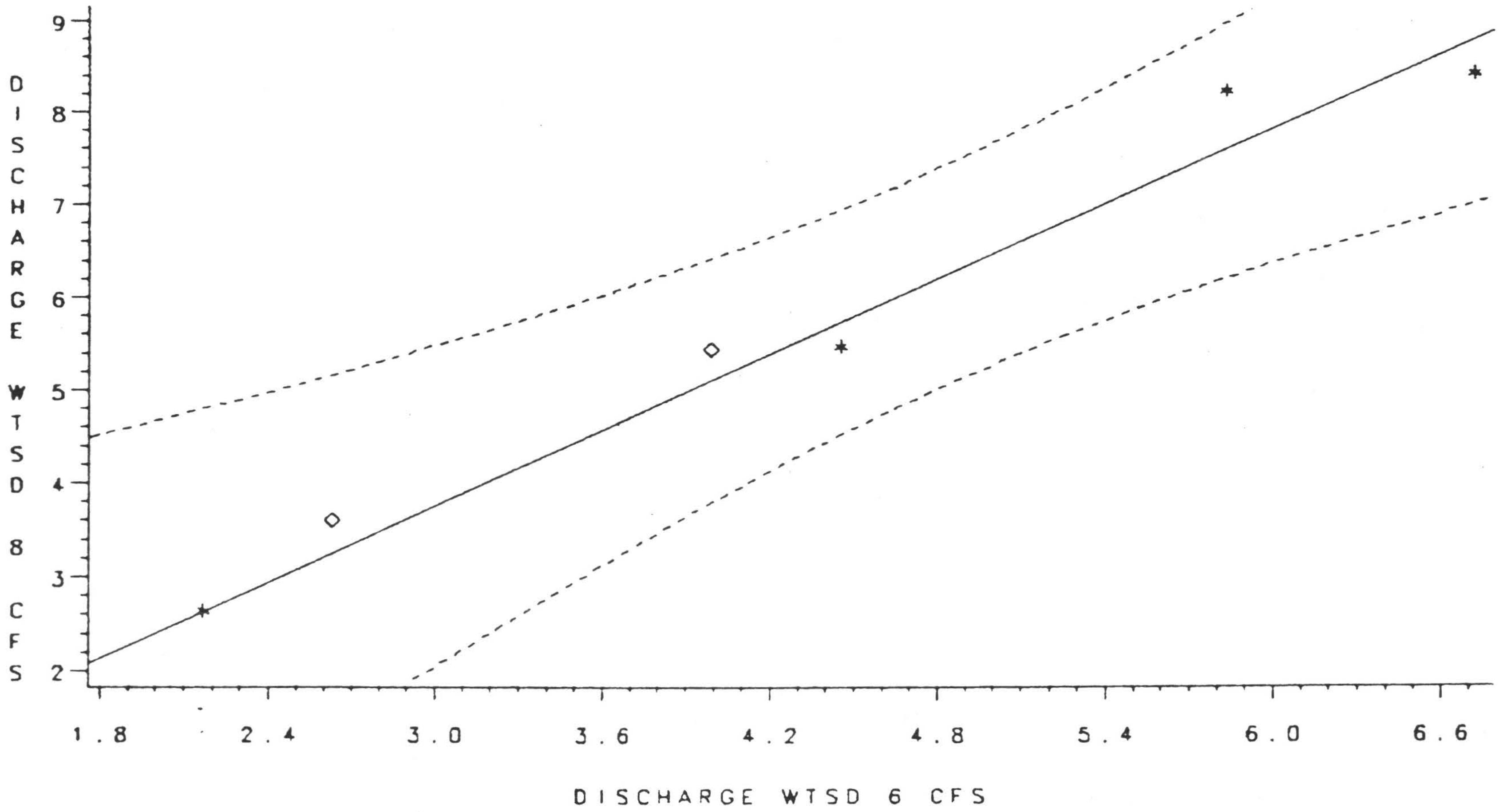
CALIBRATION--WATERSHED 18

JULIAN DATE OF PEAK



CALIBRATION--WATERSHED 8

STREAM PEAK DISCHARGE



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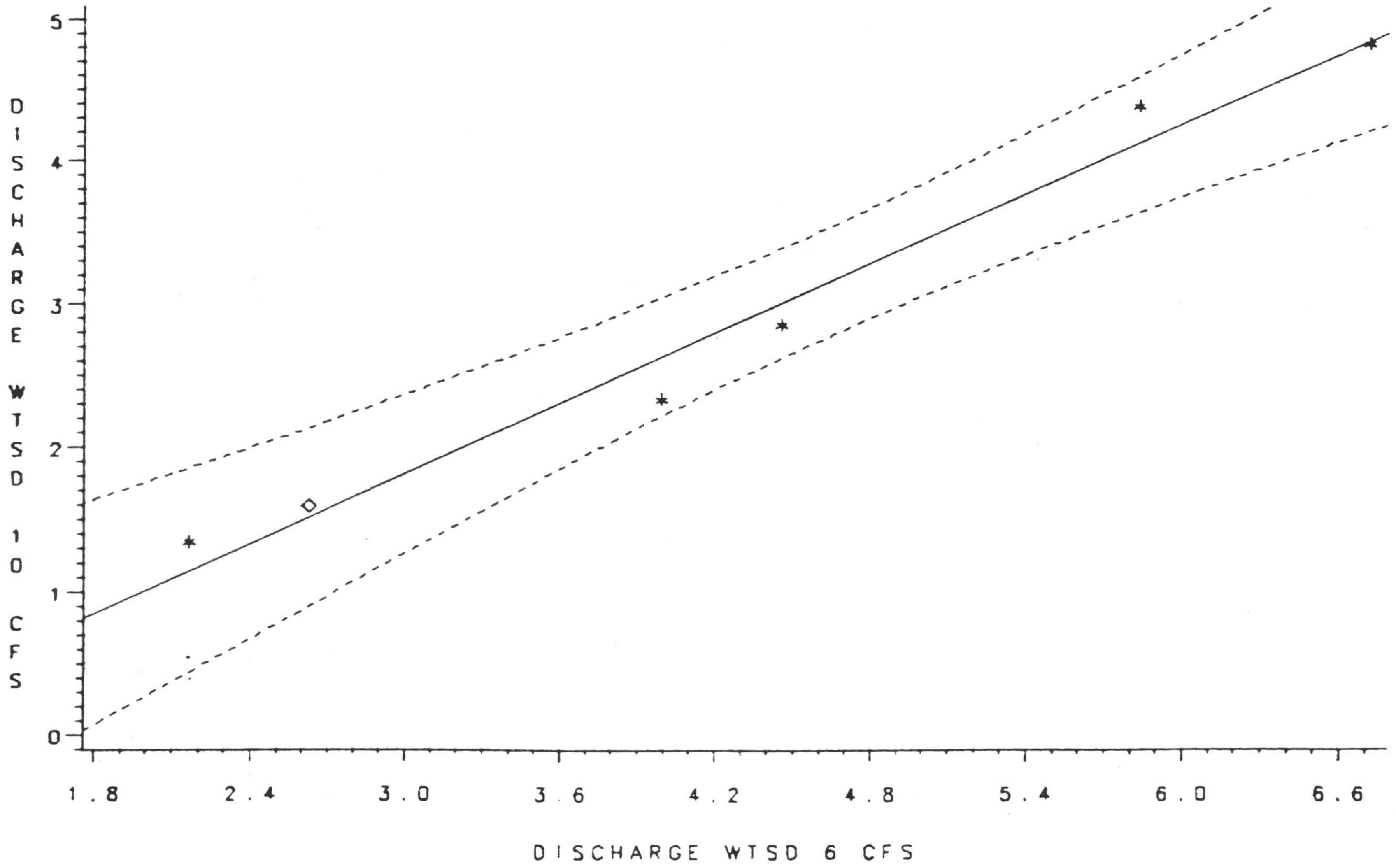
STREAM PEAK DISCHARGE



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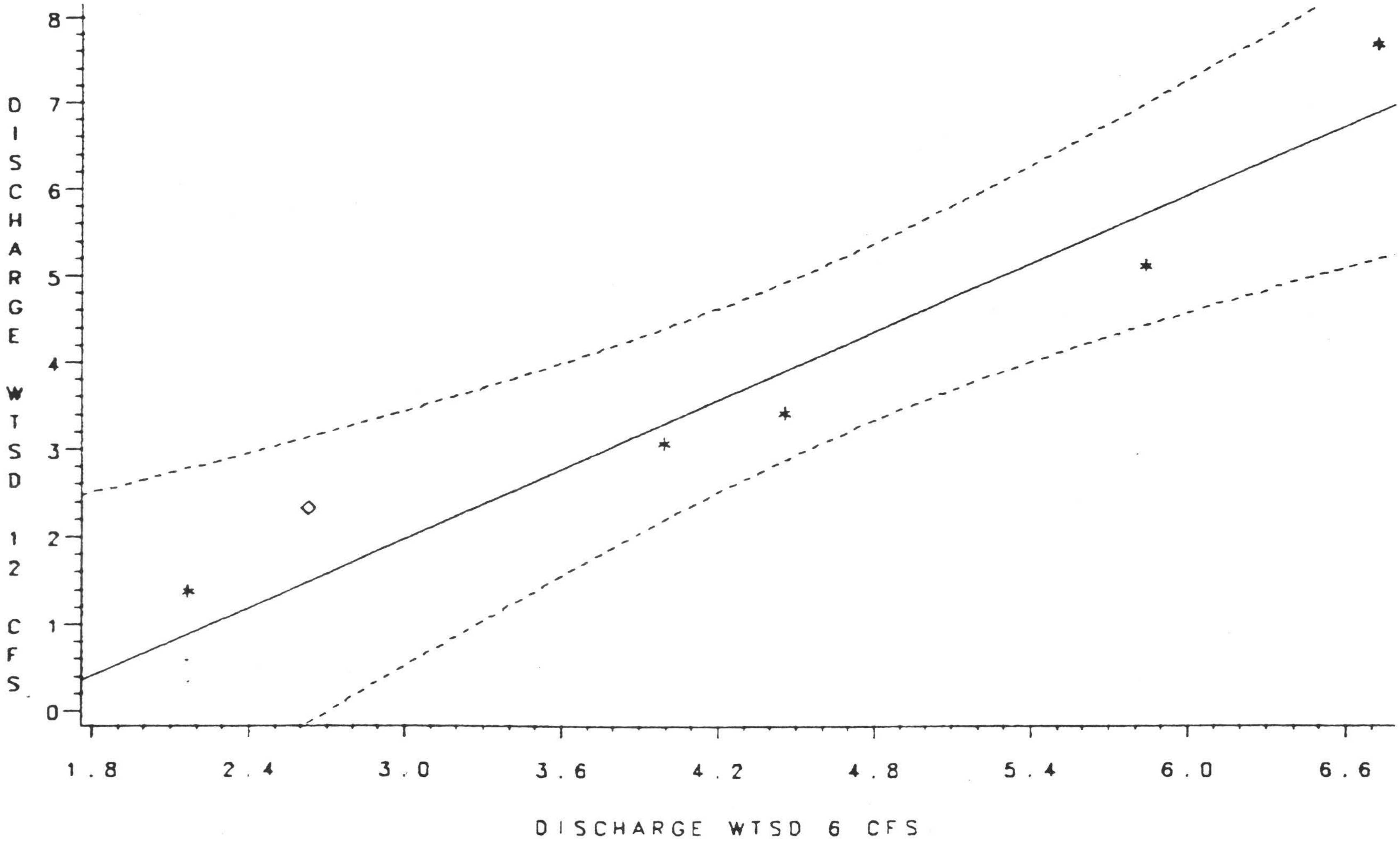
STREAM PEAK DISCHARGE



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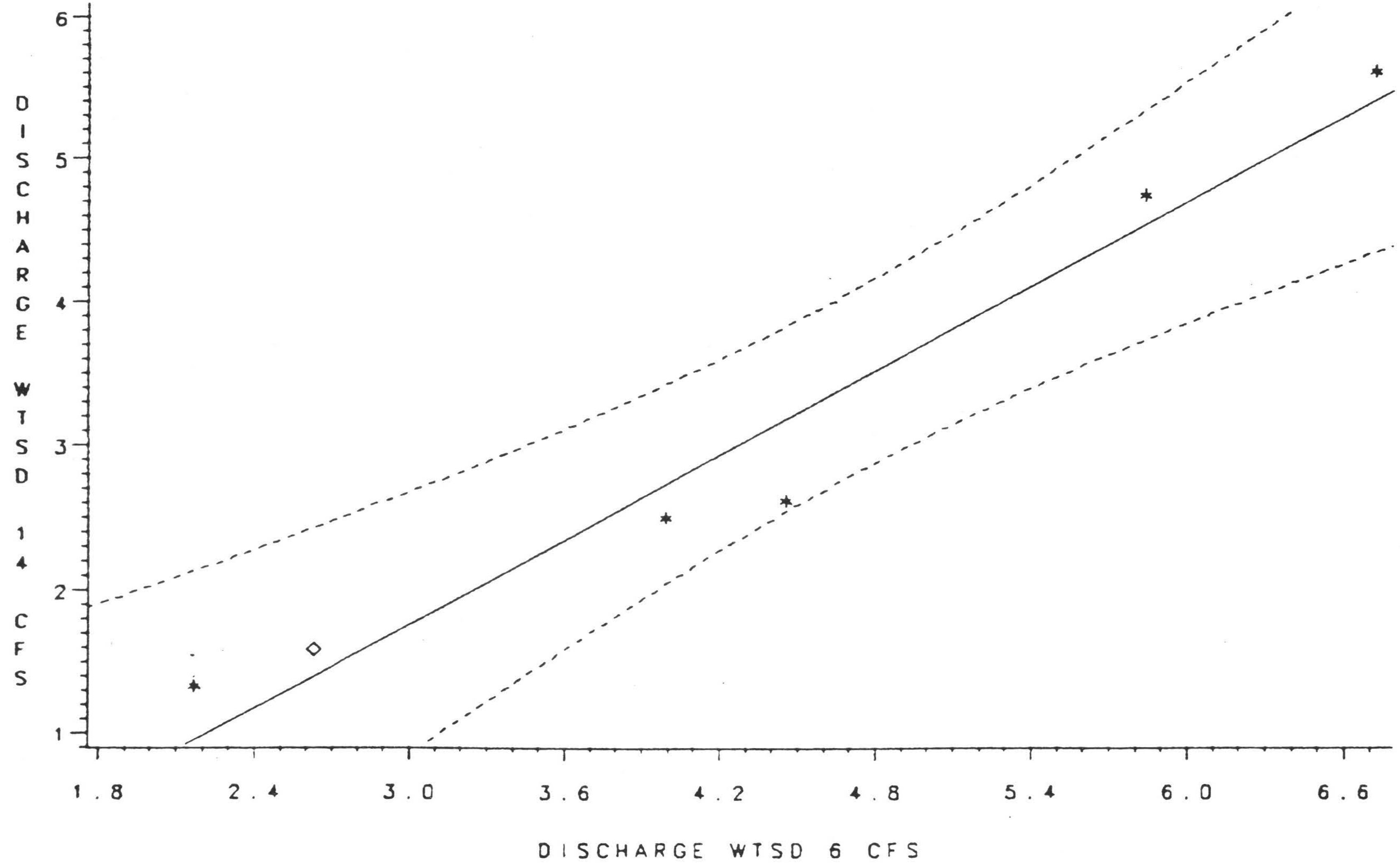
STREAM PEAK DISCHARGE



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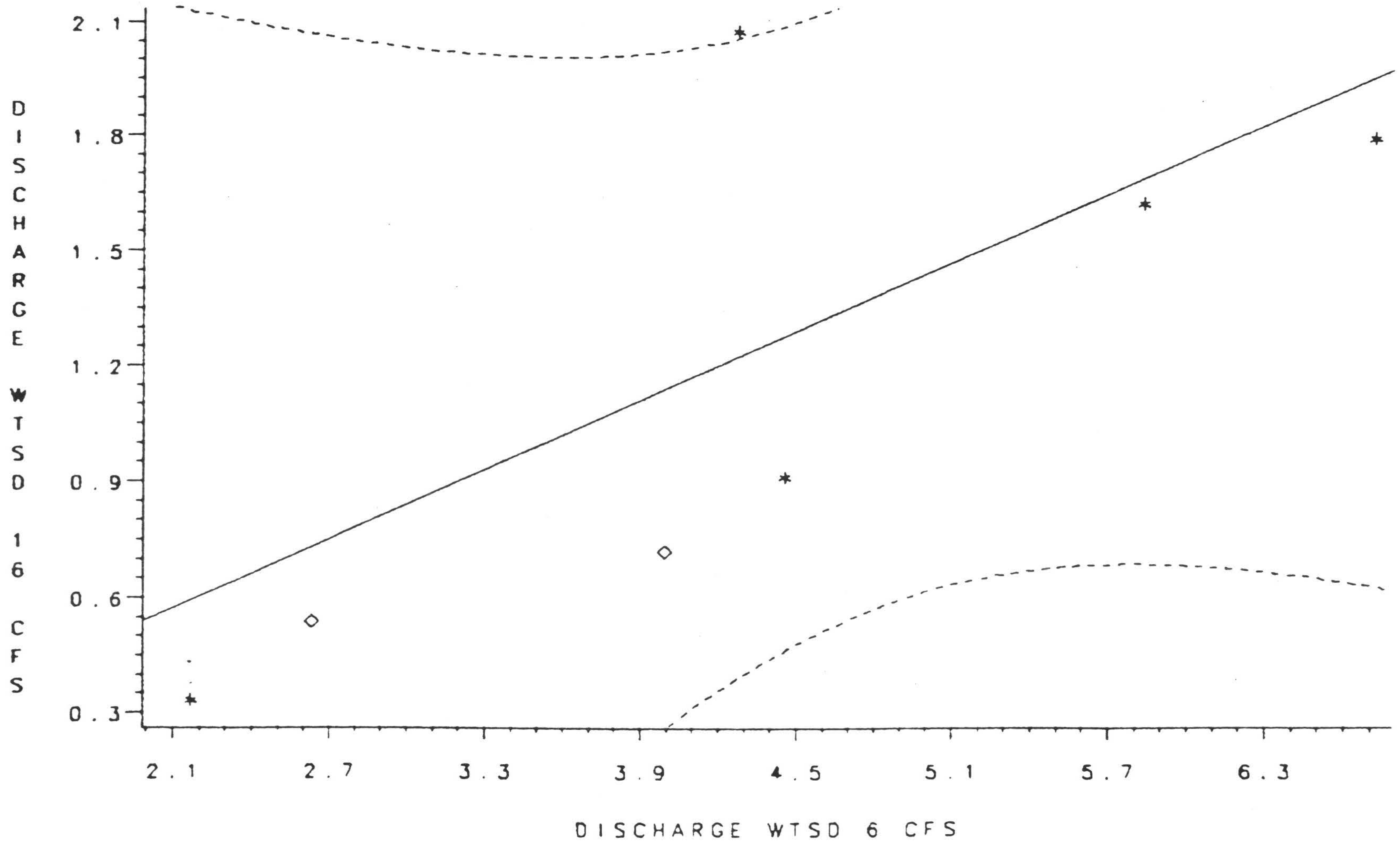
STREAM PEAK DISCHARGE



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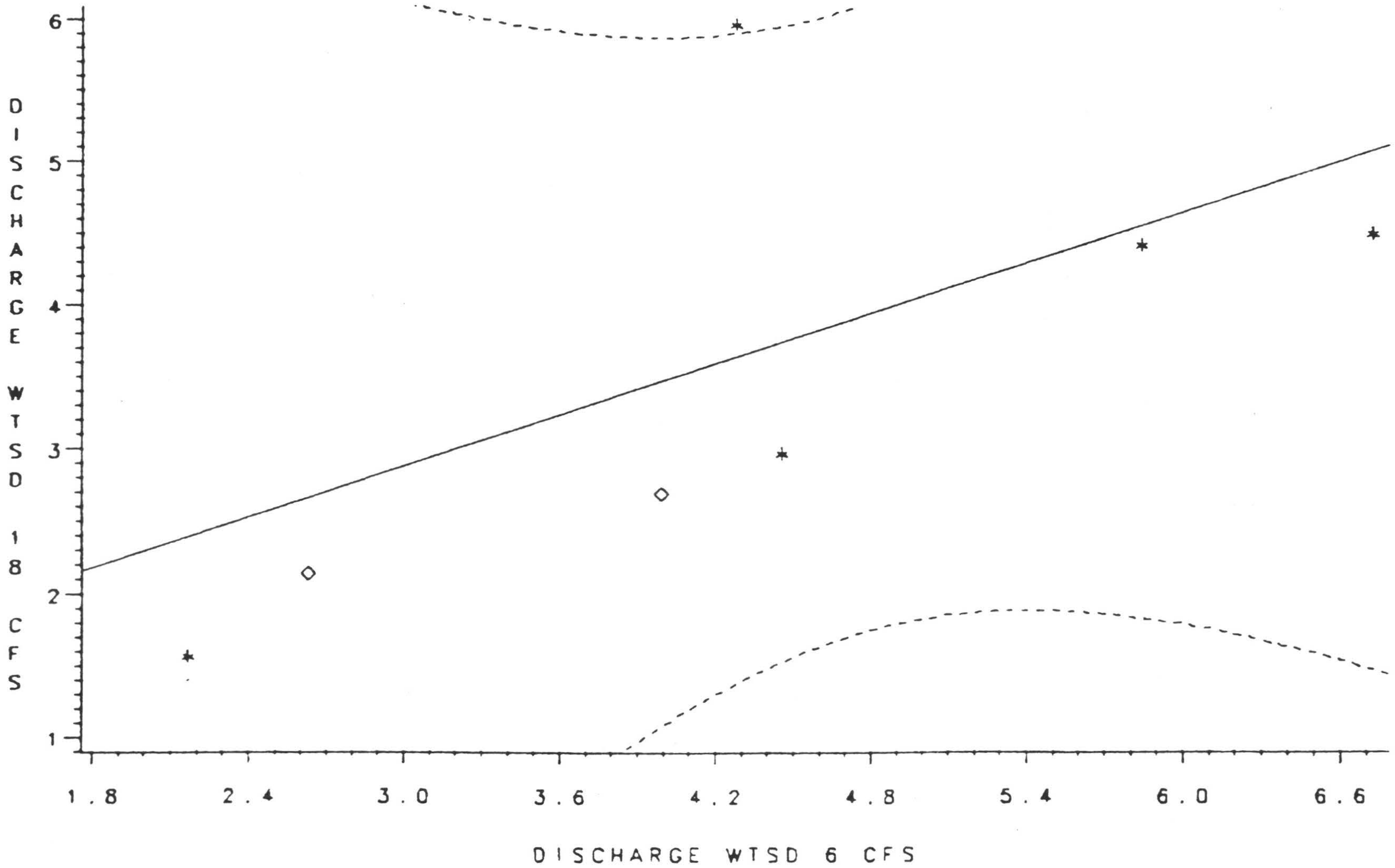
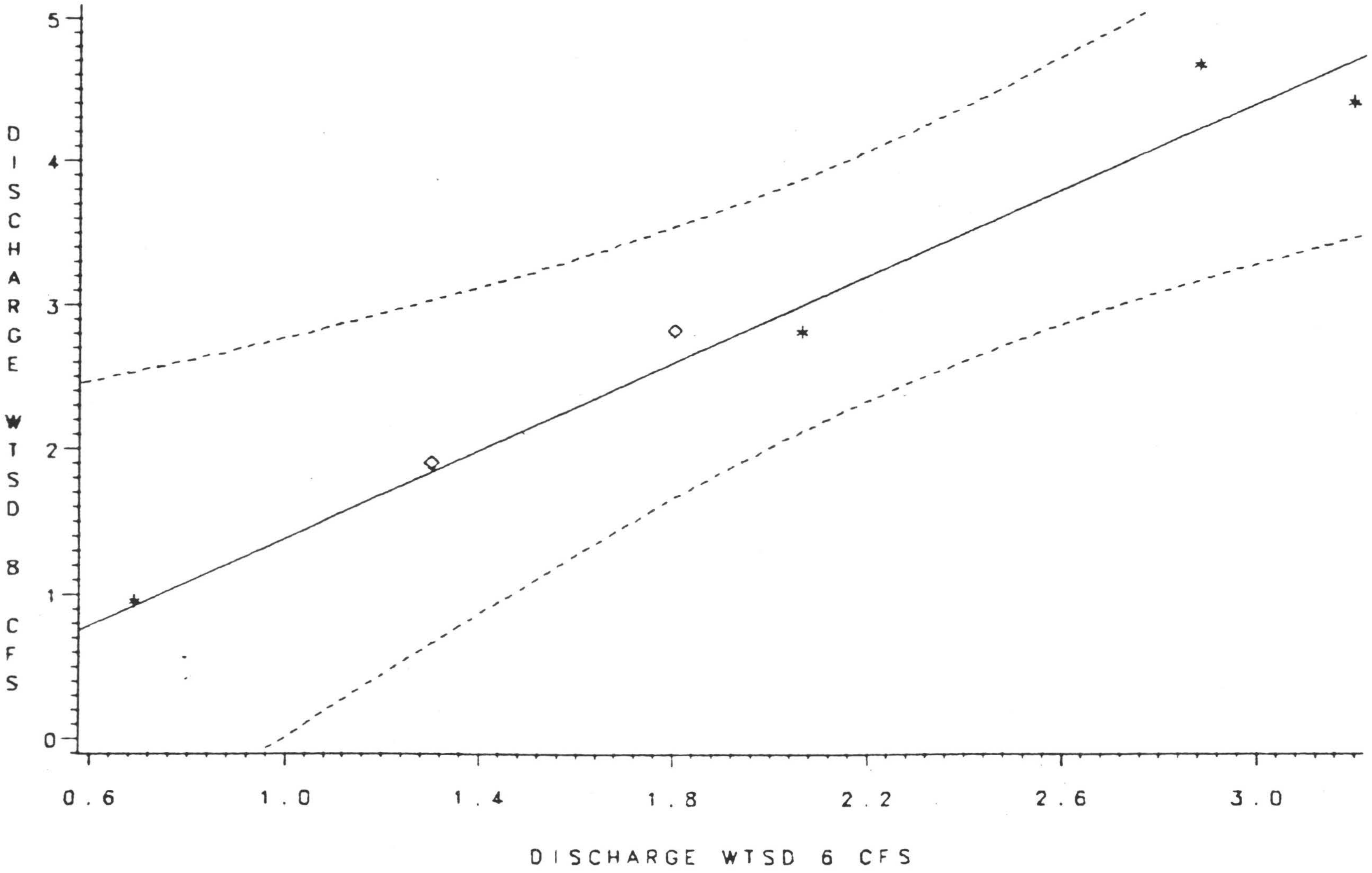
STREAM PEAK DISCHARGE



CALIBRATION--WATERSHED 8

STREAM DISCHARGE EQUALLED OR EXCEEDED 5 PER CENT OF THE TIME



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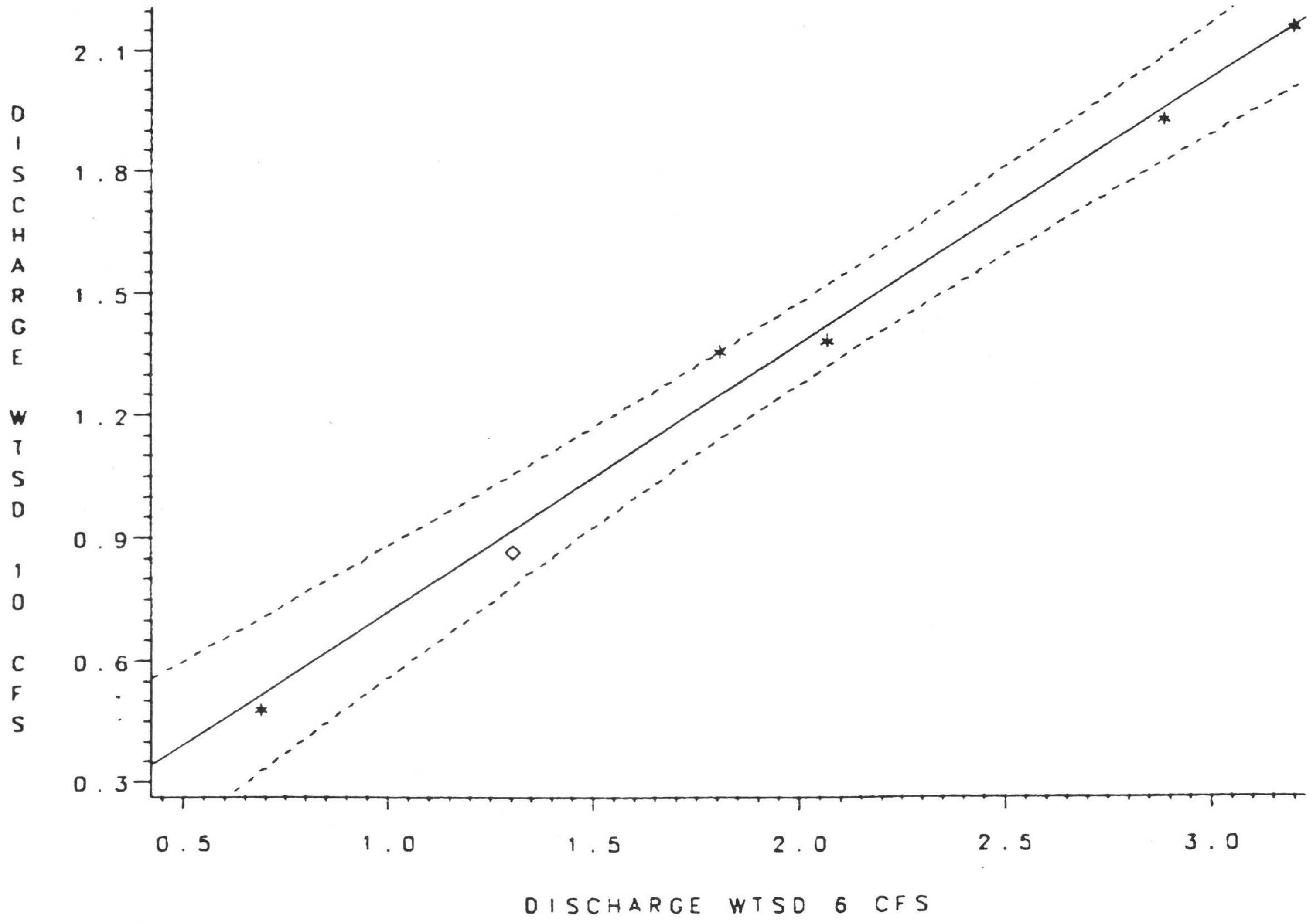

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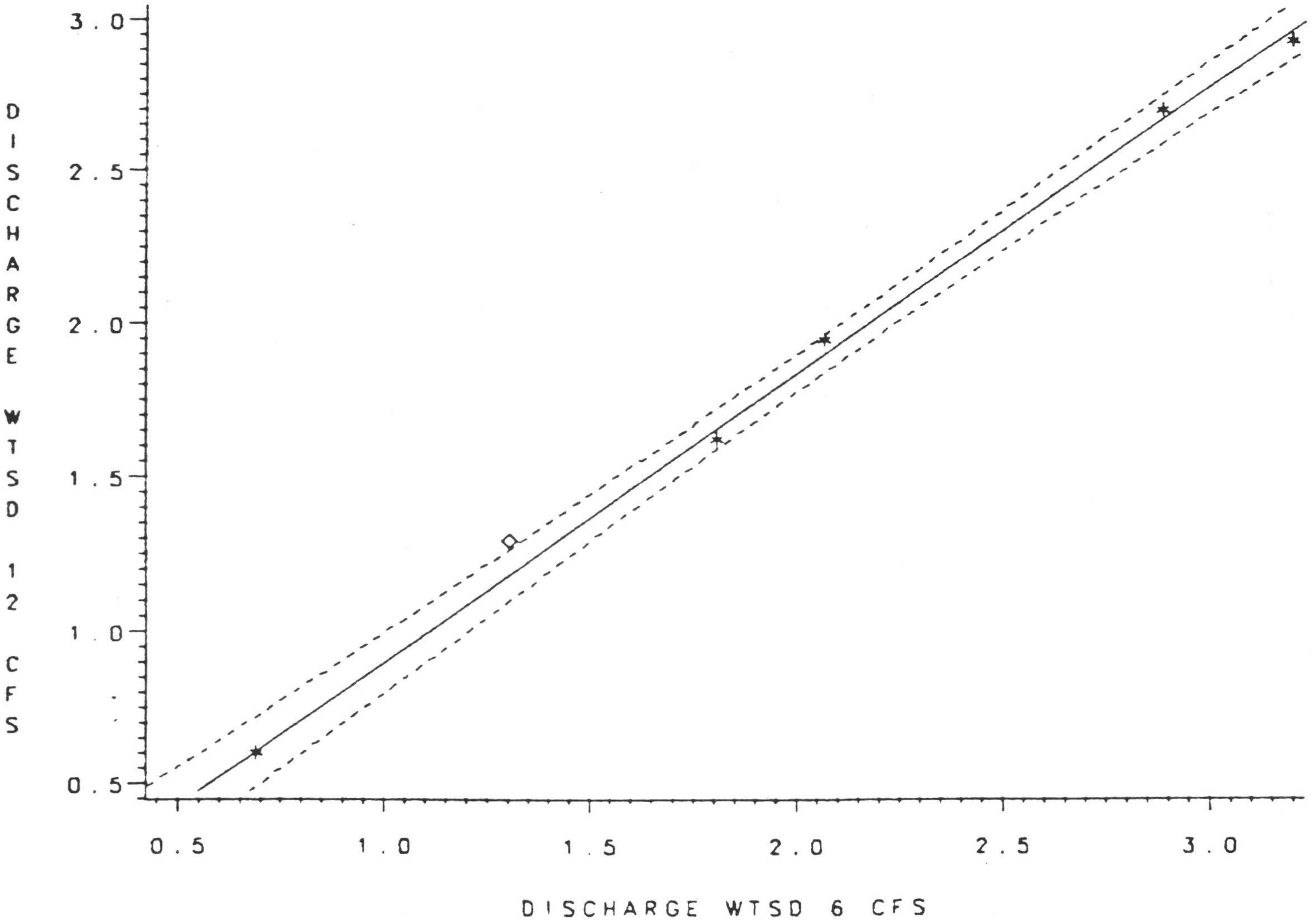
STREAM DISCHARGE EQUALLED OR EXCEEDED 5 PER CENT OF THE TIME



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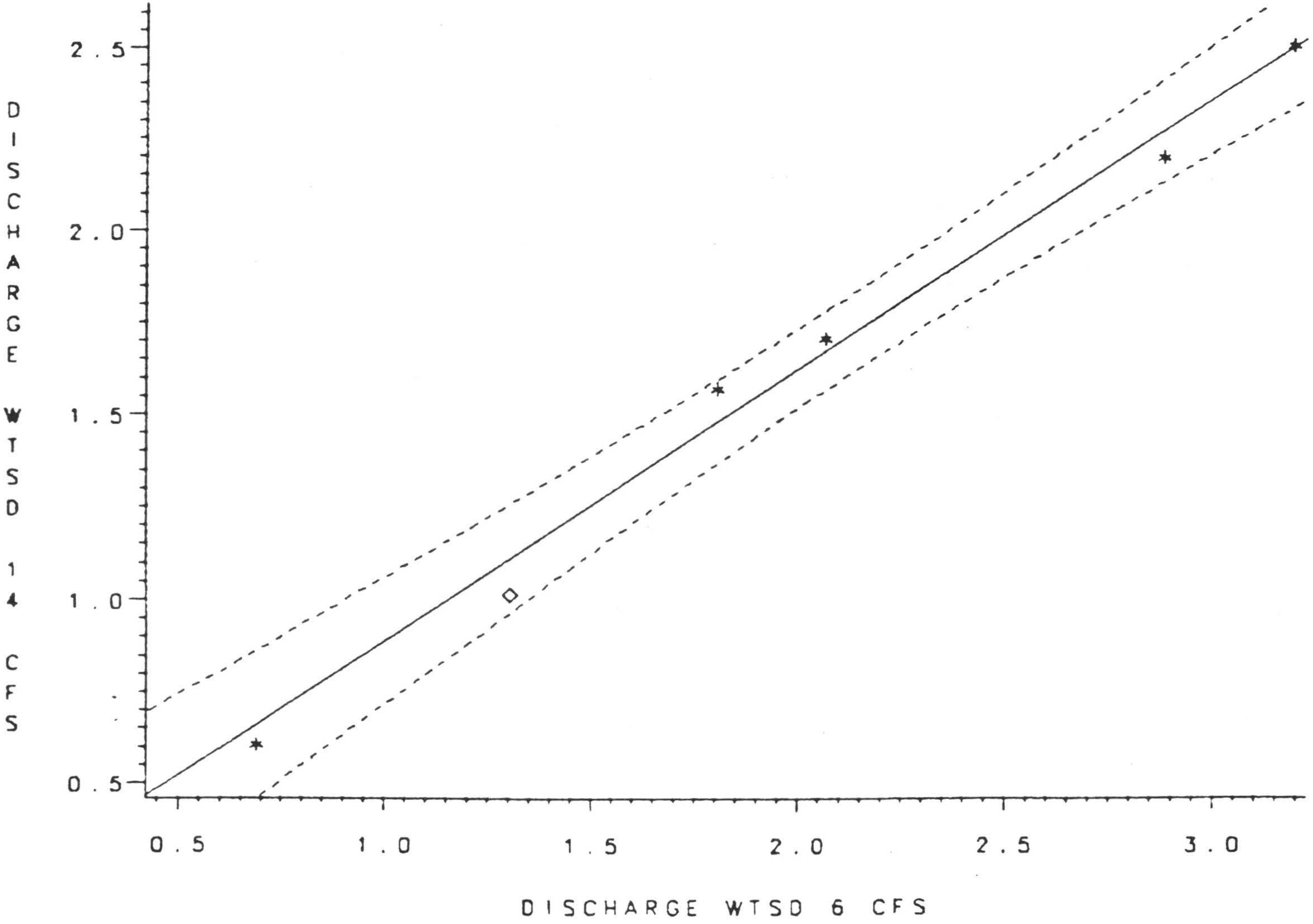
STREAM DISCHARGE EQUALLED OR EXCEEDED 5 PER CENT OF THE TIME



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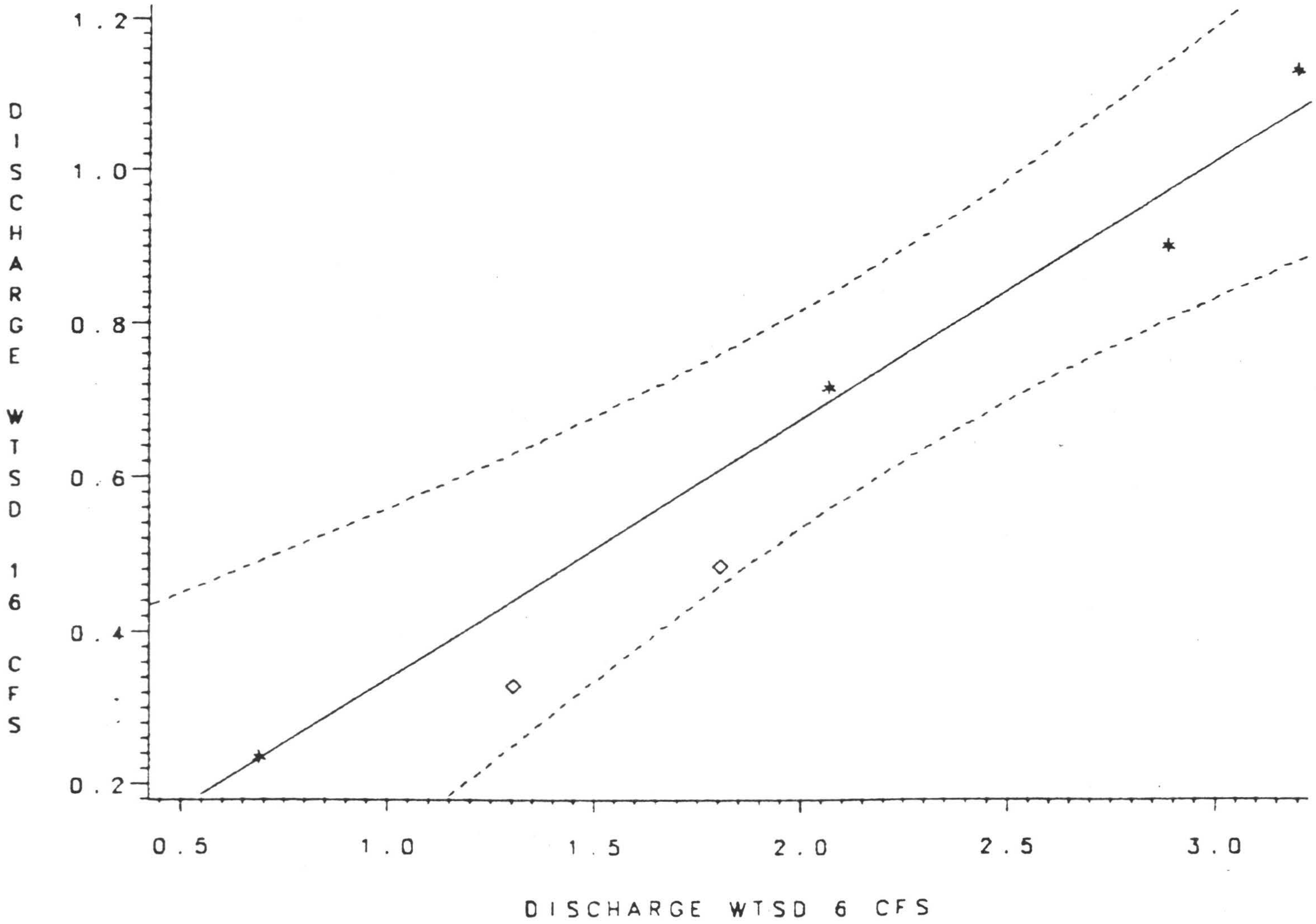
STREAM DISCHARGE EQUALLED OR EXCEEDED 5 PER CENT OF THE TIME



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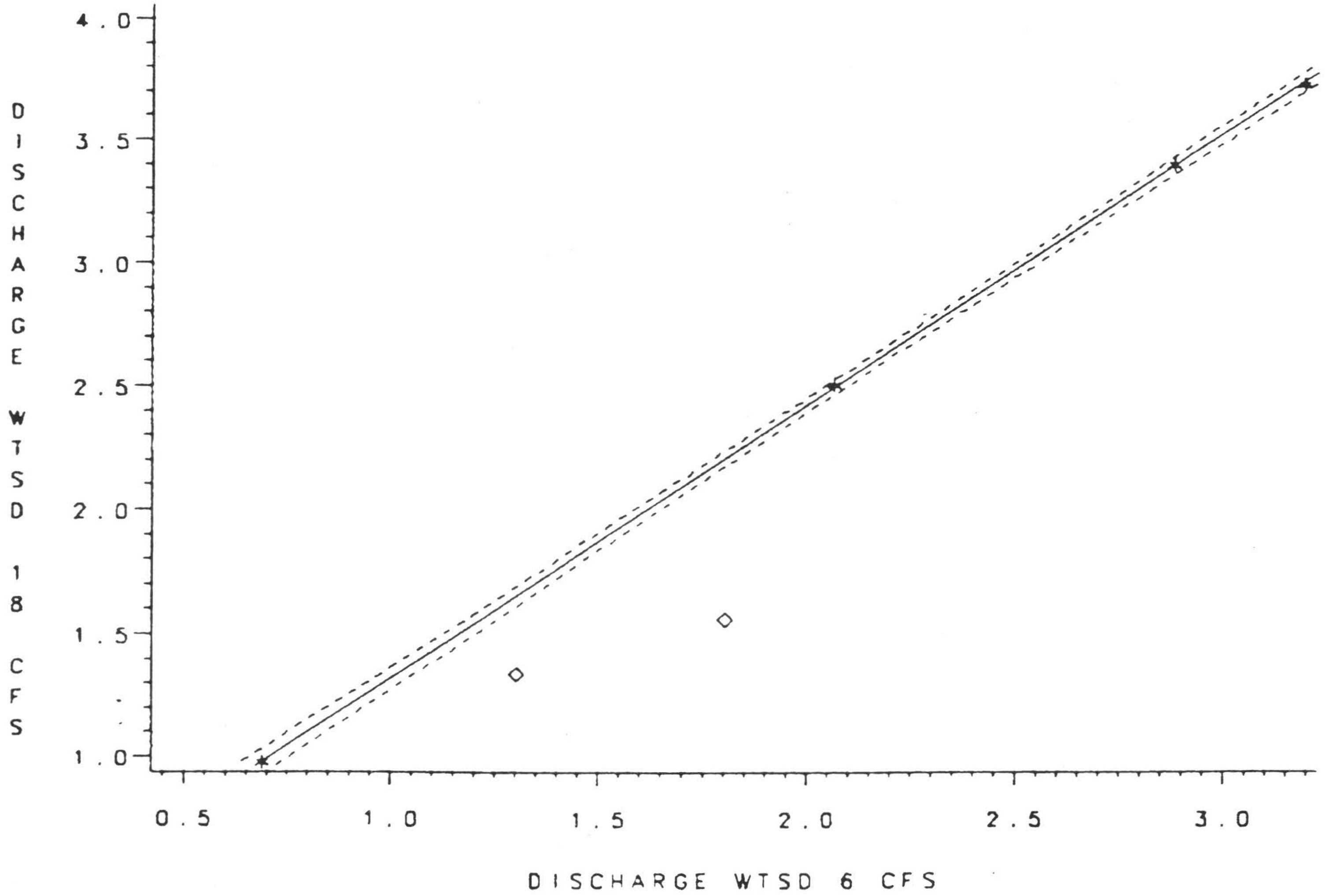
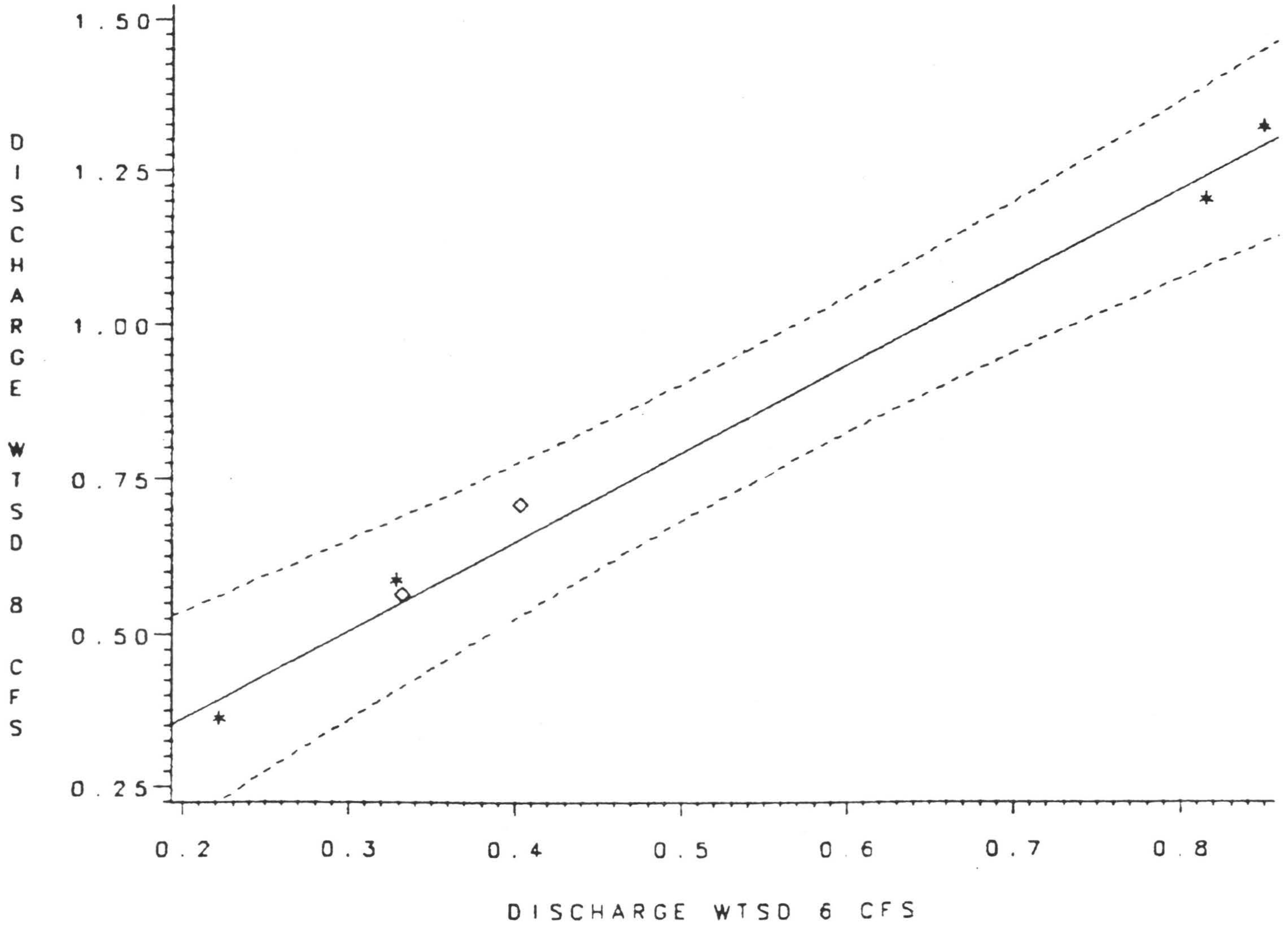
STREAM DISCHARGE EQUALLED OR EXCEEDED 5 PER CENT OF THE TIME



CALIBRATION--WATERSHED 8

STREAM DISCHARGE EQUALLED OR EXCEEDED 25 PER CENT OF TIME



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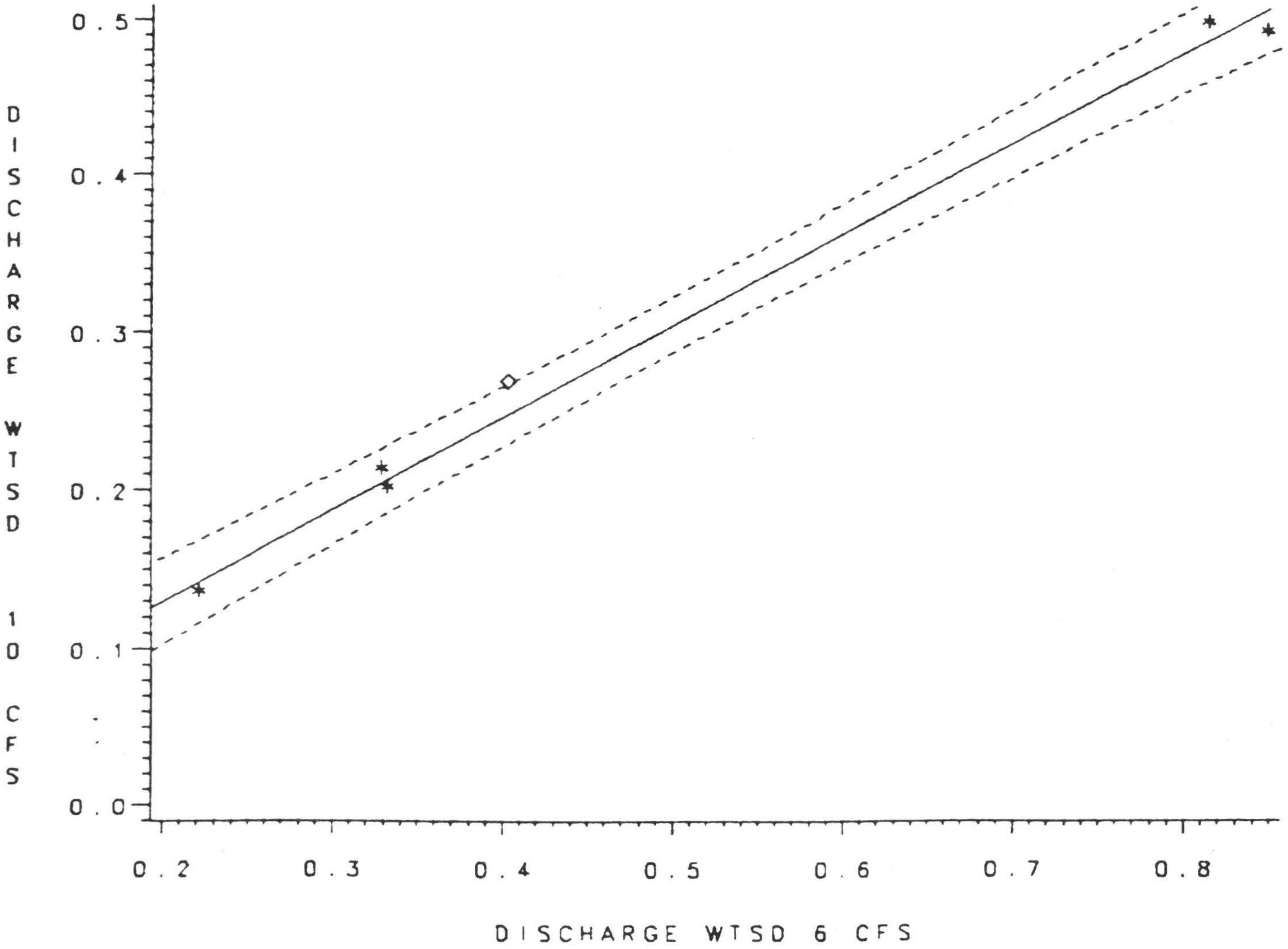

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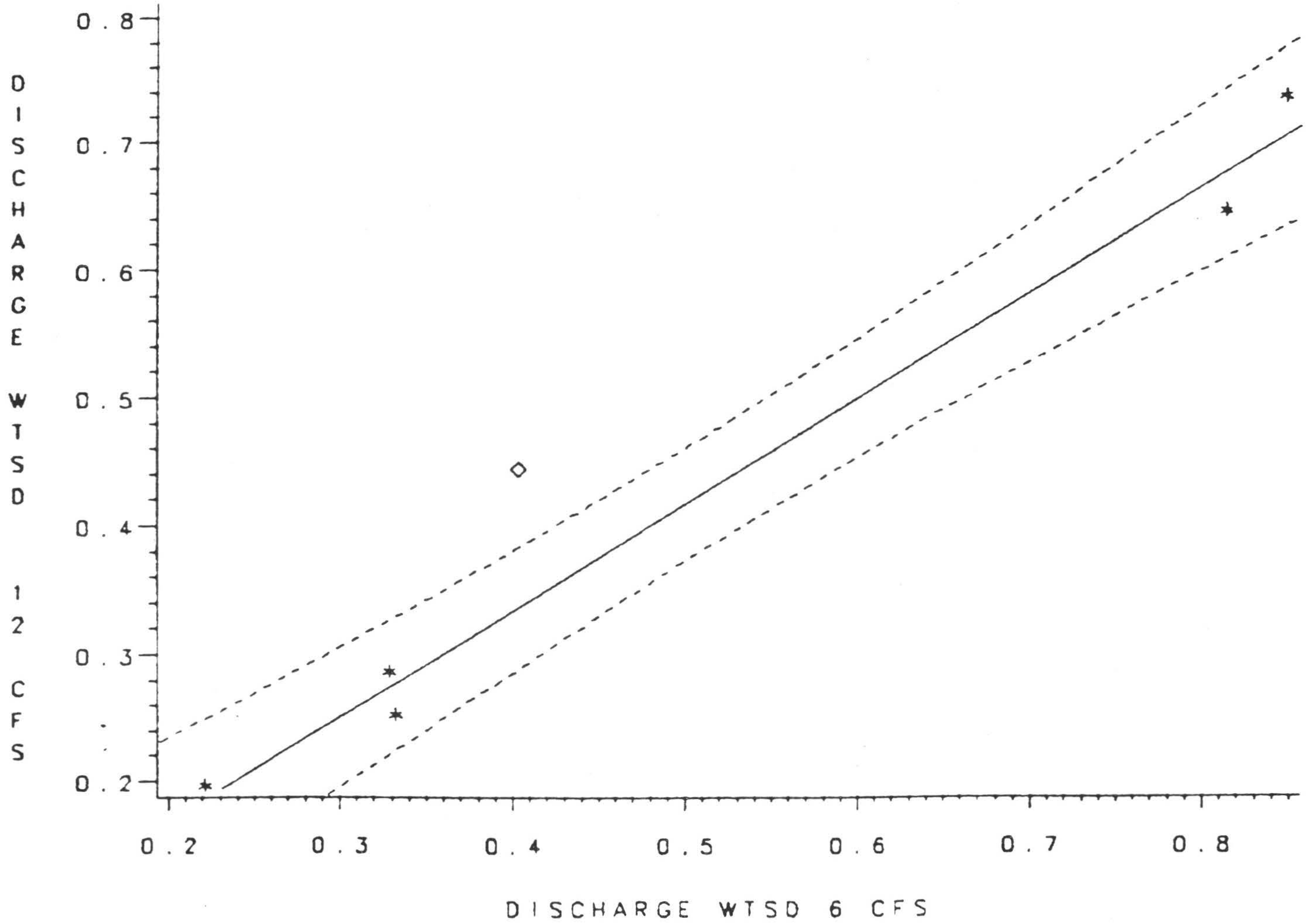

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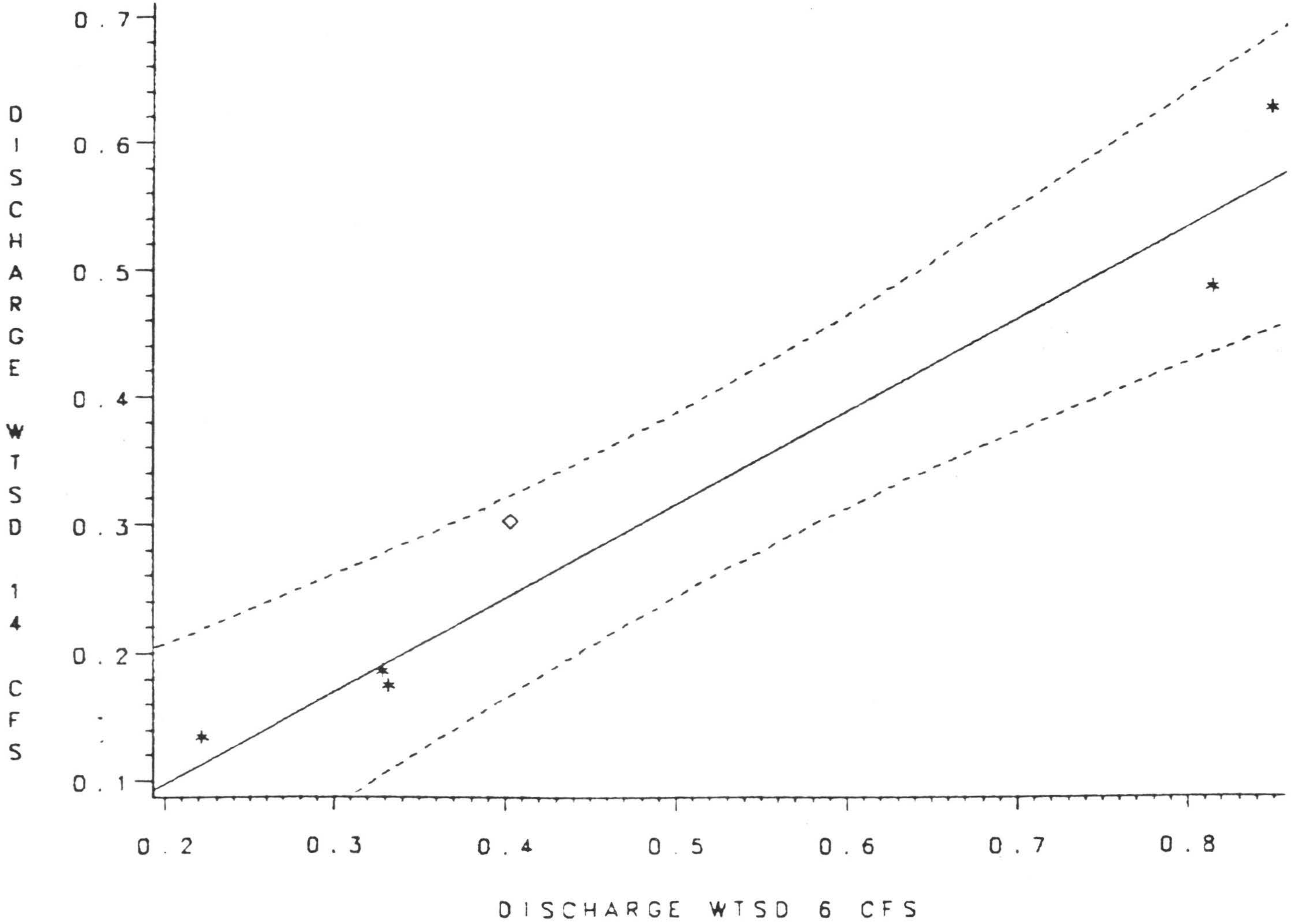

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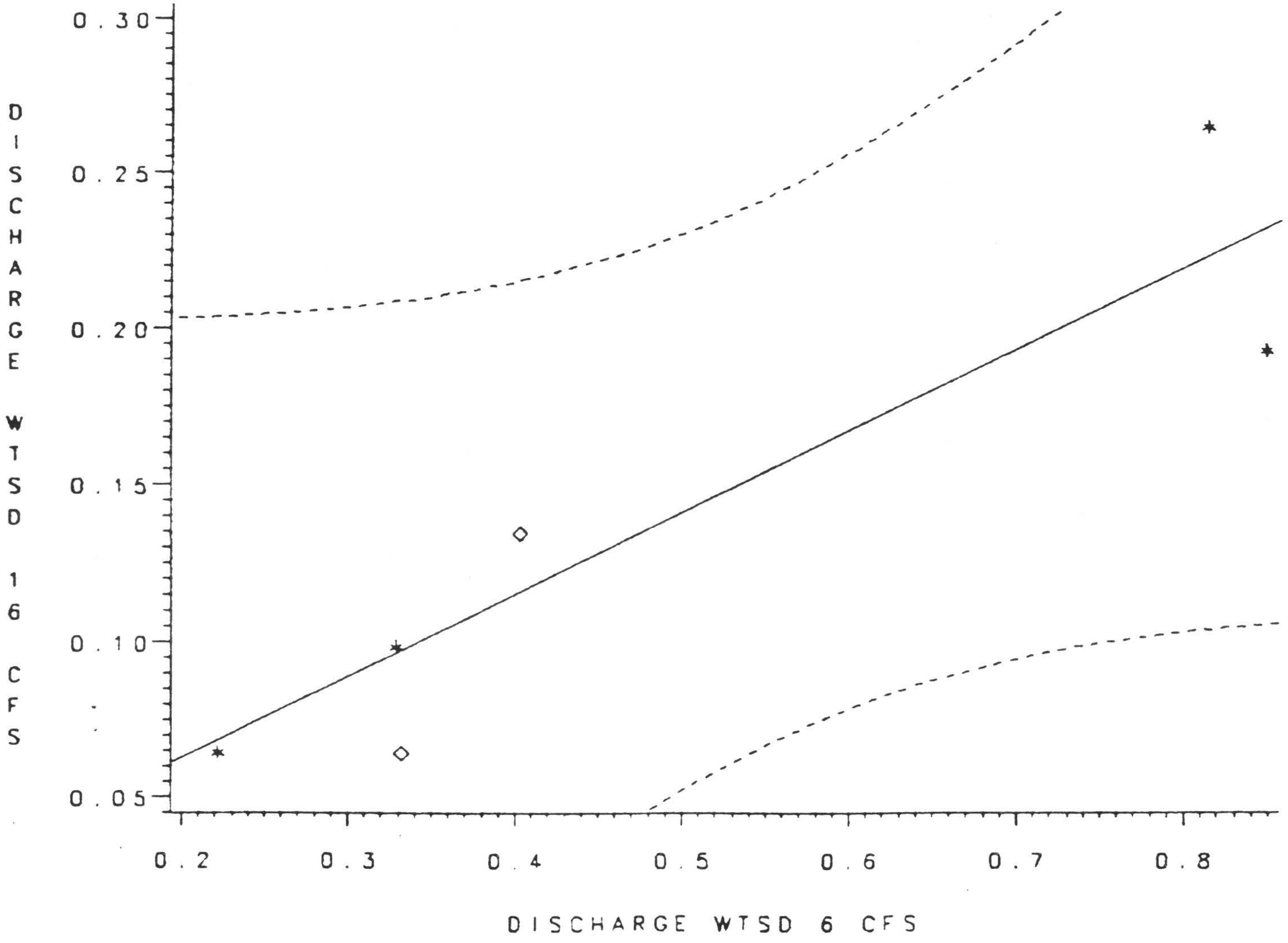

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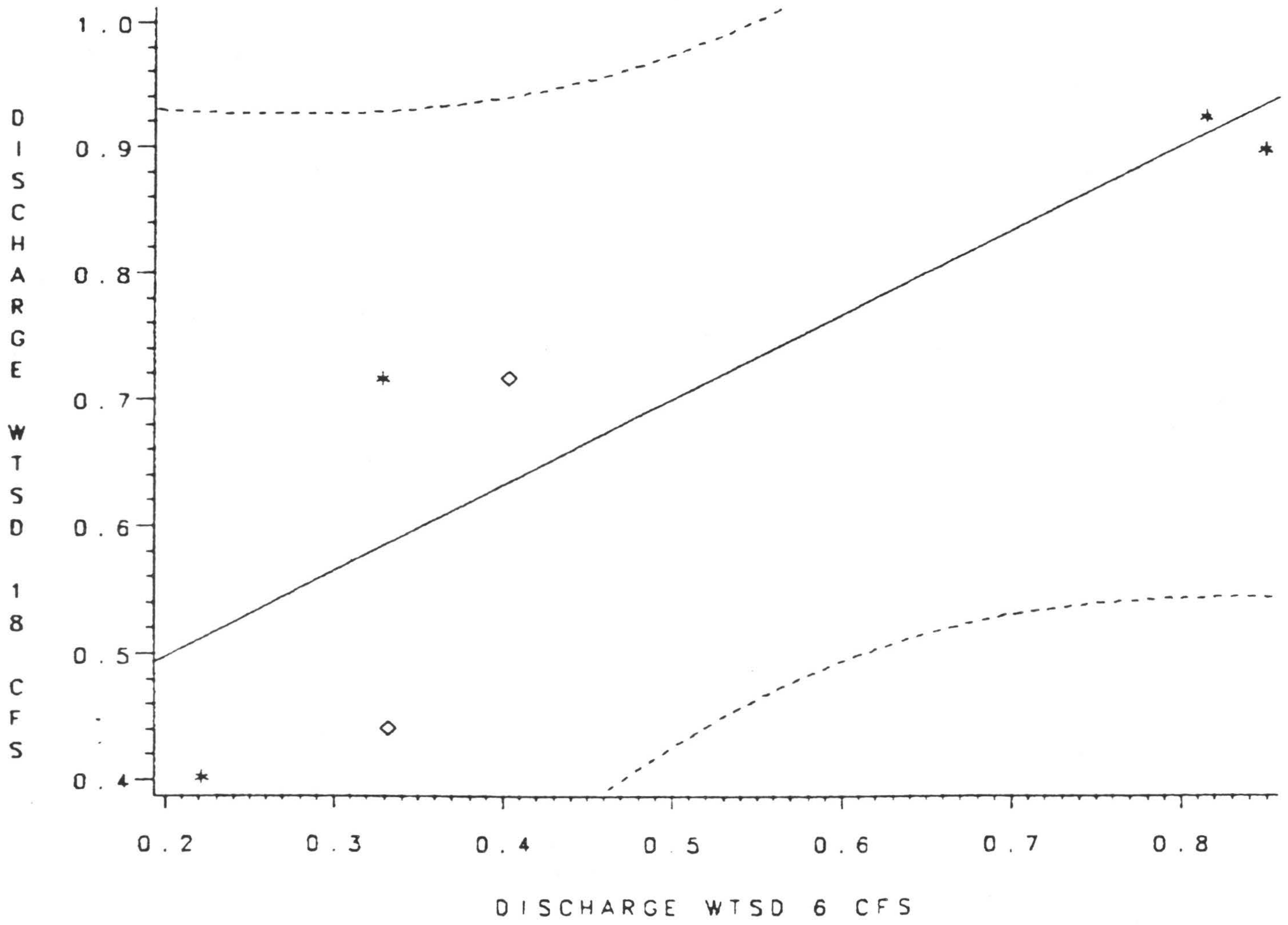
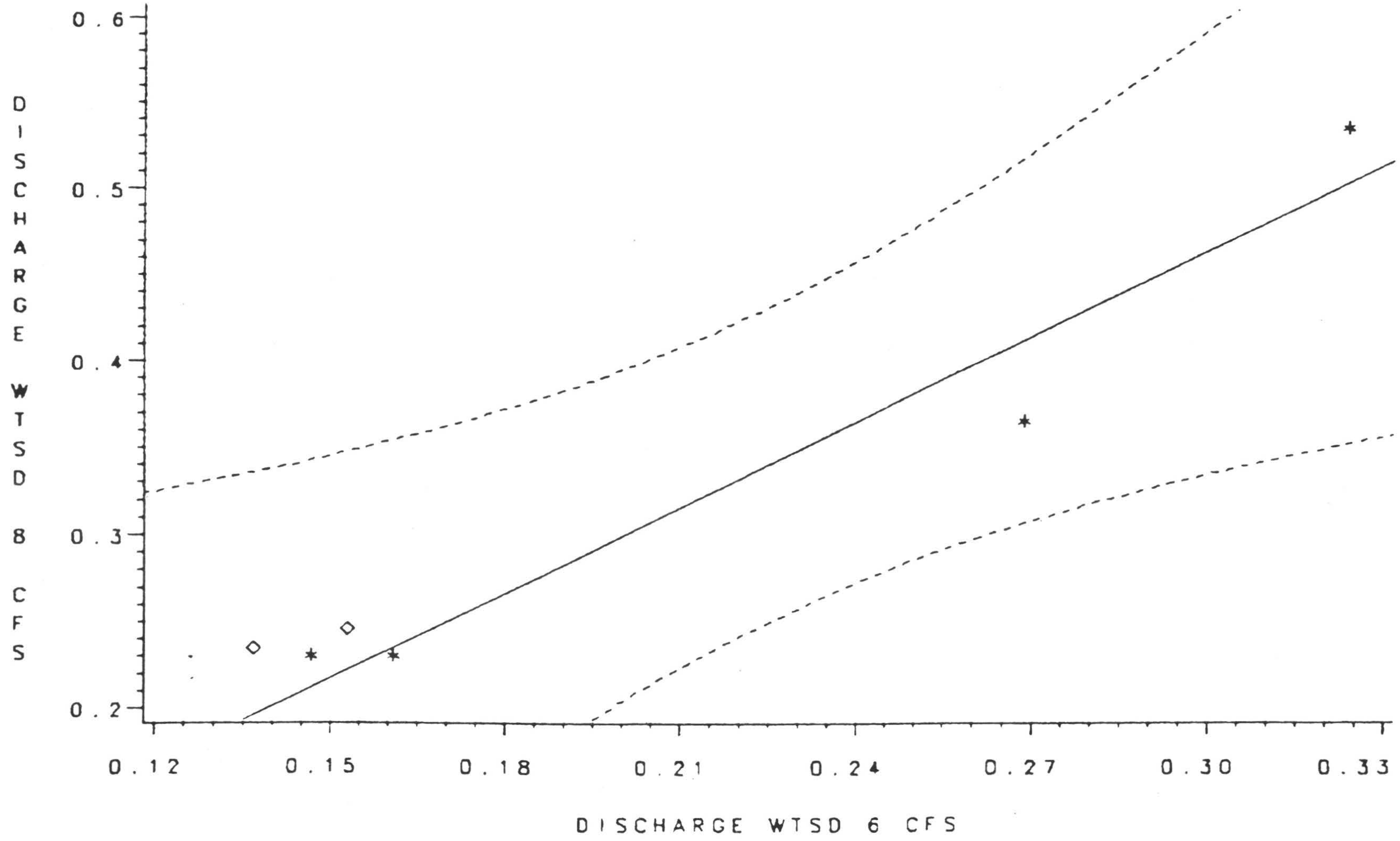
STREAM DISCHARGE EQUALLED OR EXCEEDED 25 PER CENT OF THE TIME



CALIBRATION--WATERSHED 8

STREAM DISCHARGE EQUALLED OR EXCEEDED 75 PER CENT OF TIME



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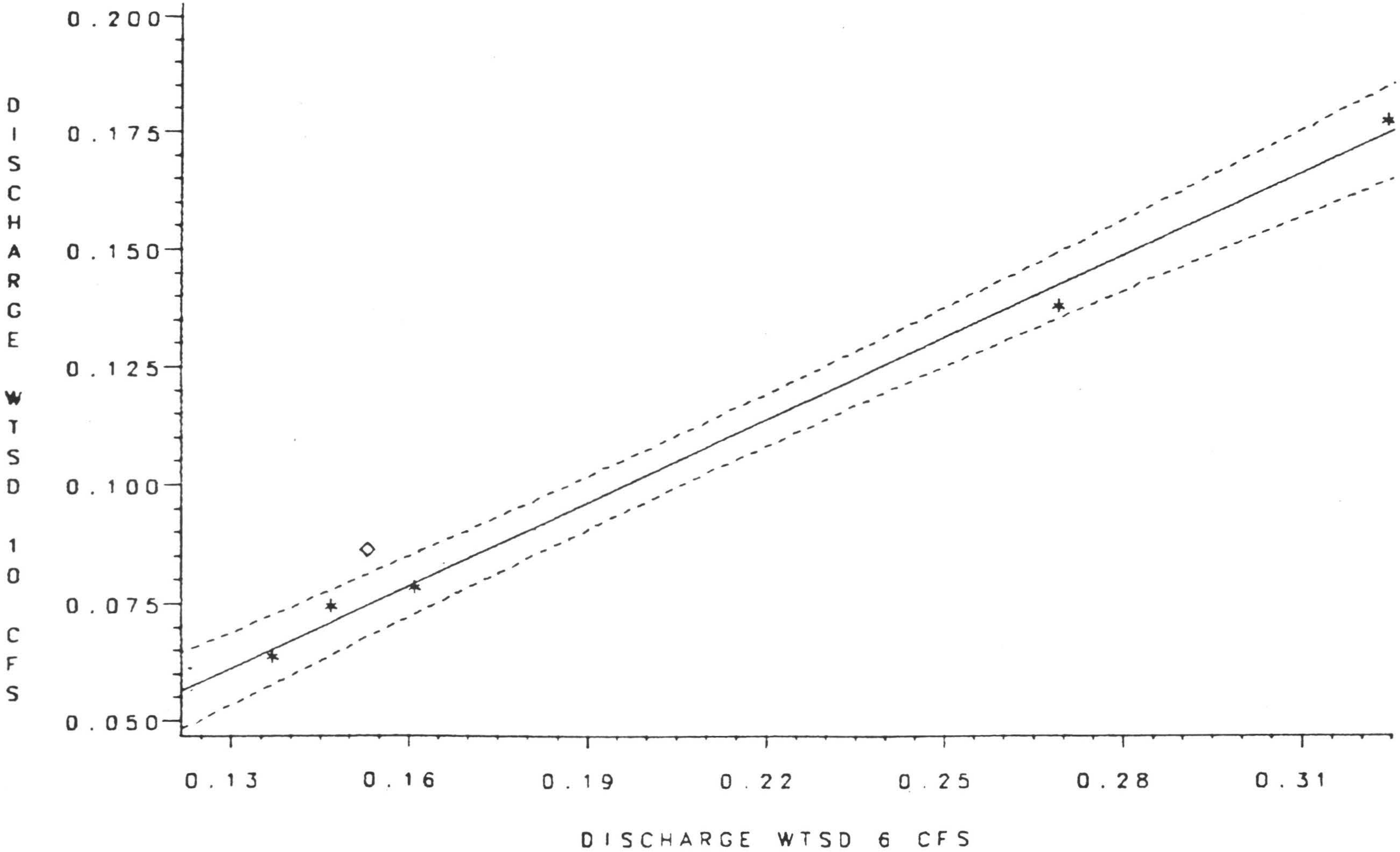

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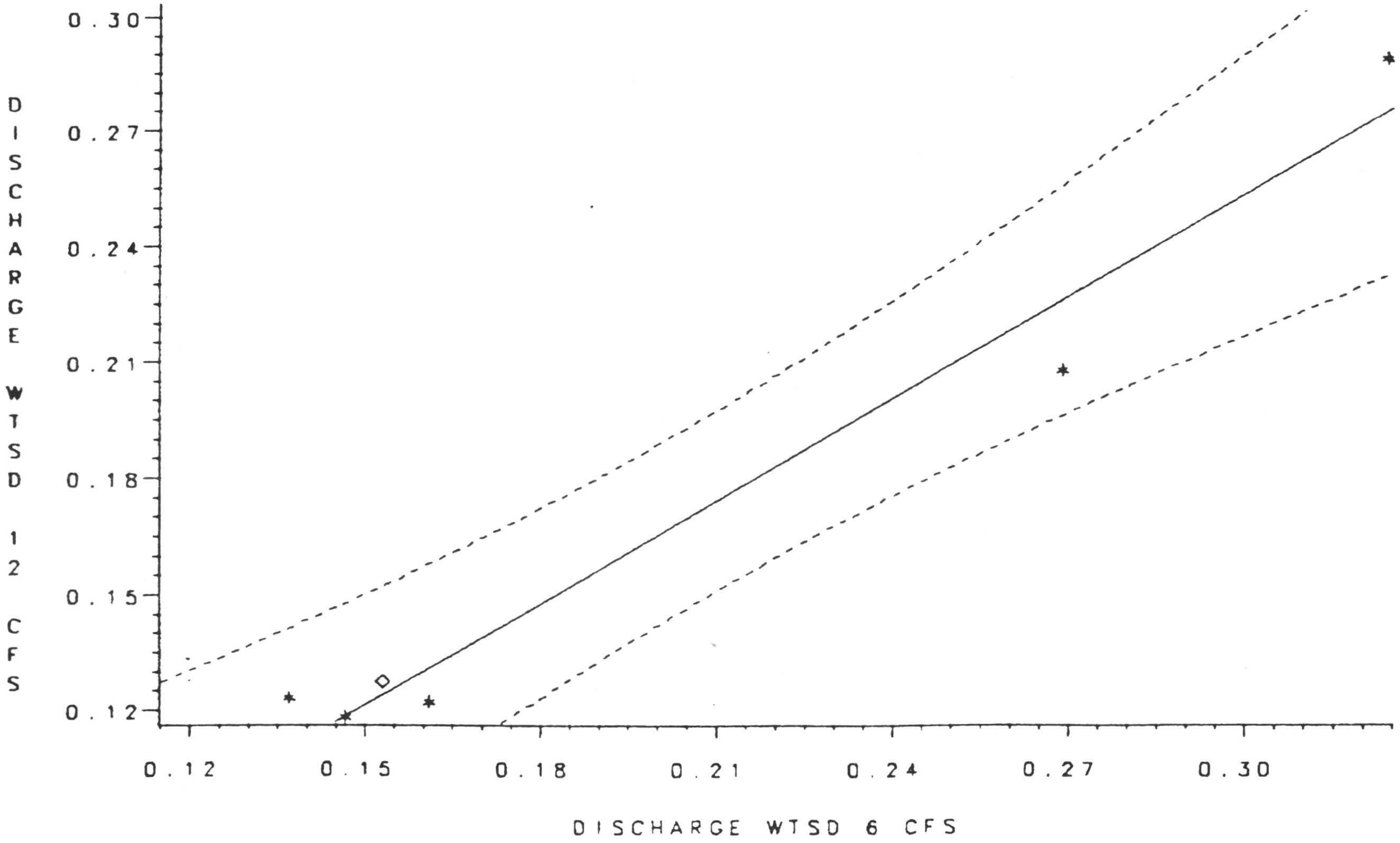

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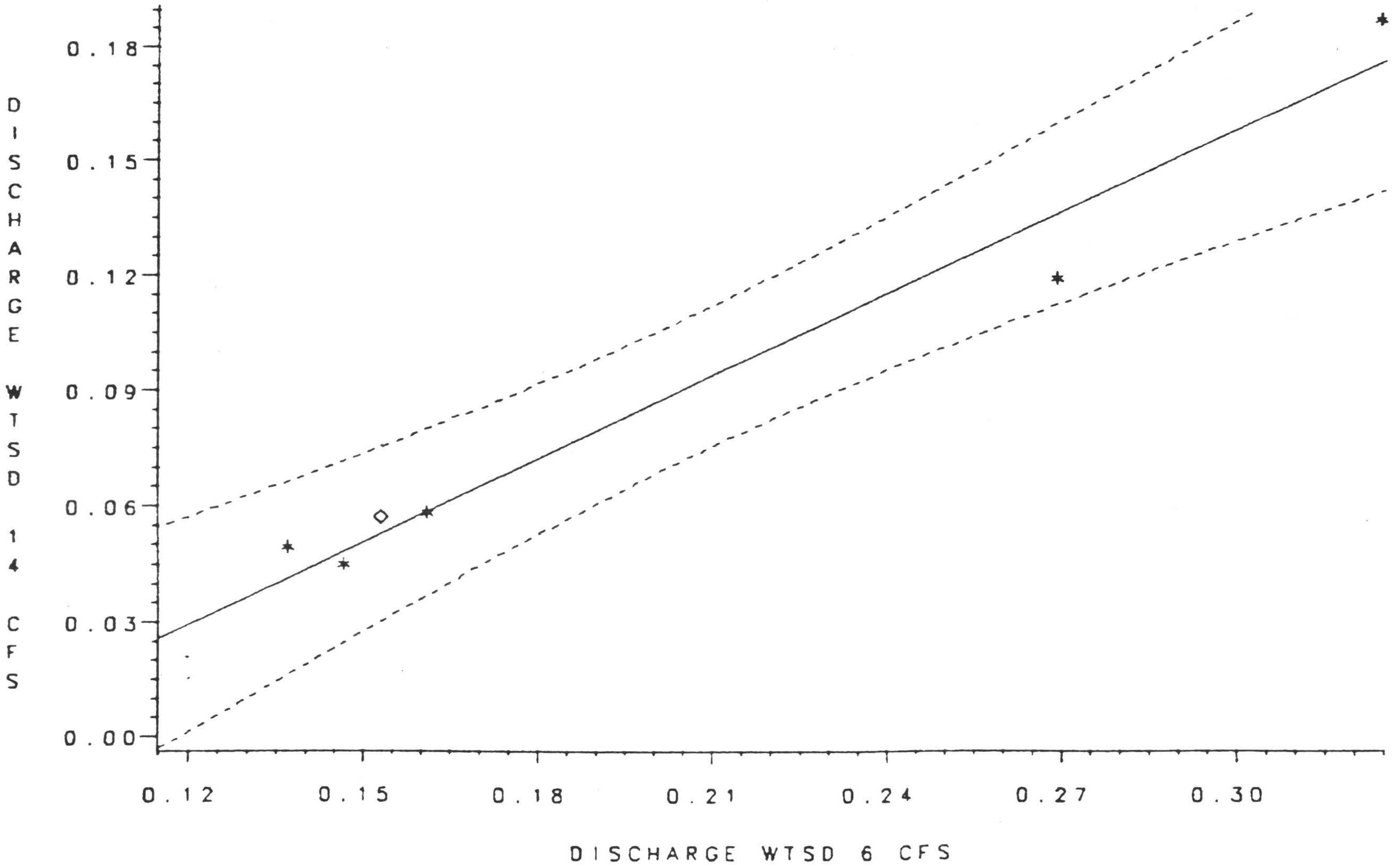

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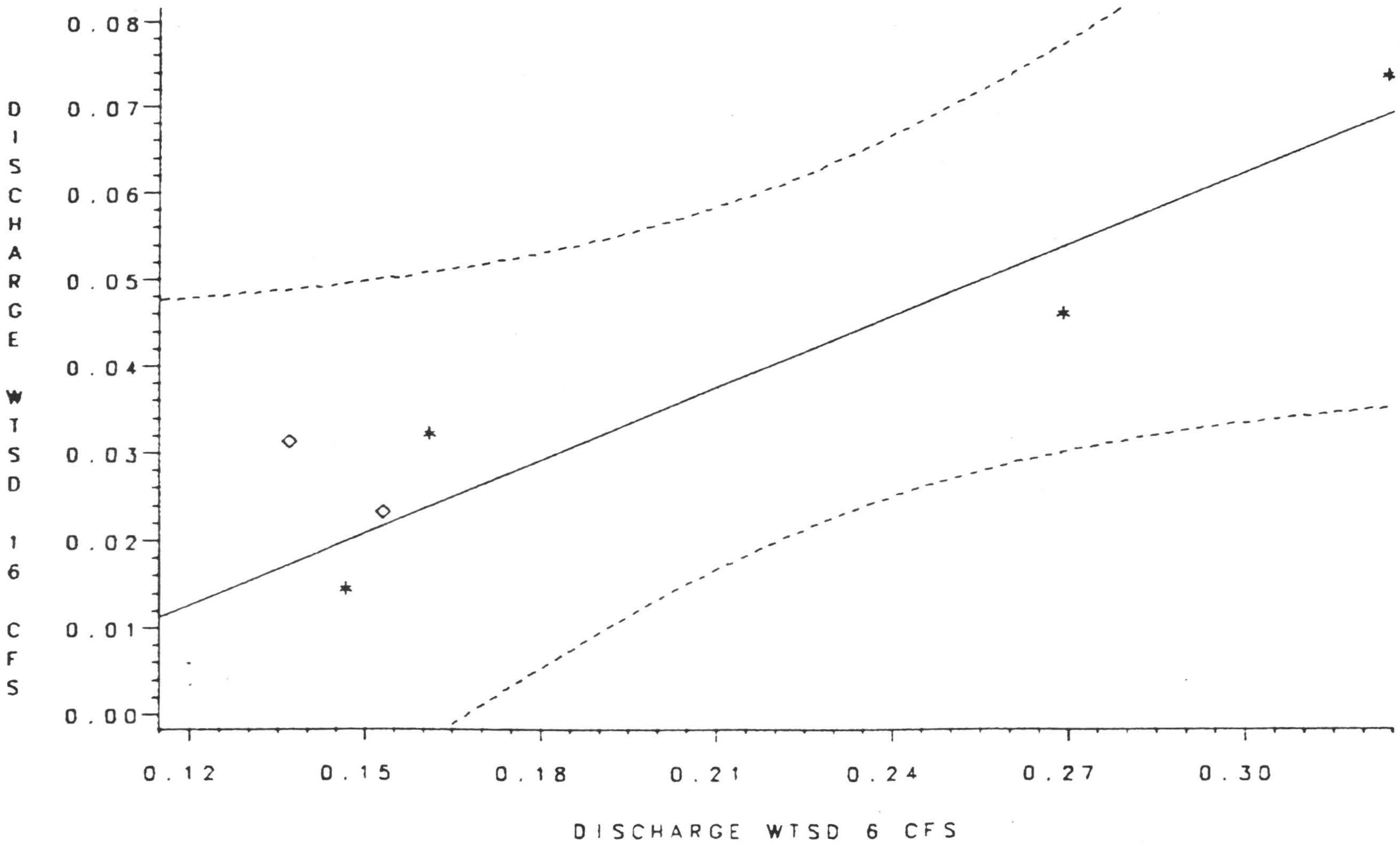

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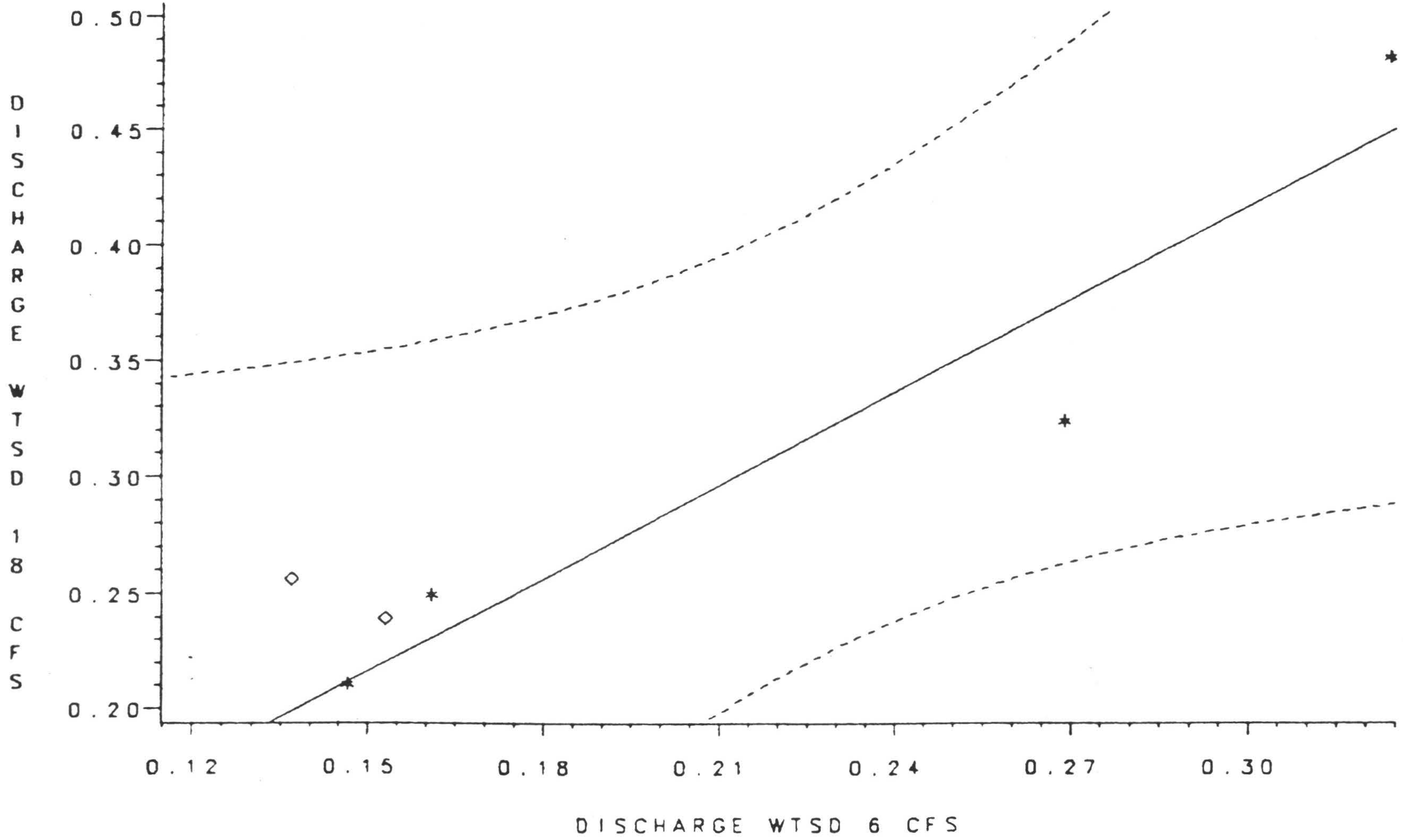
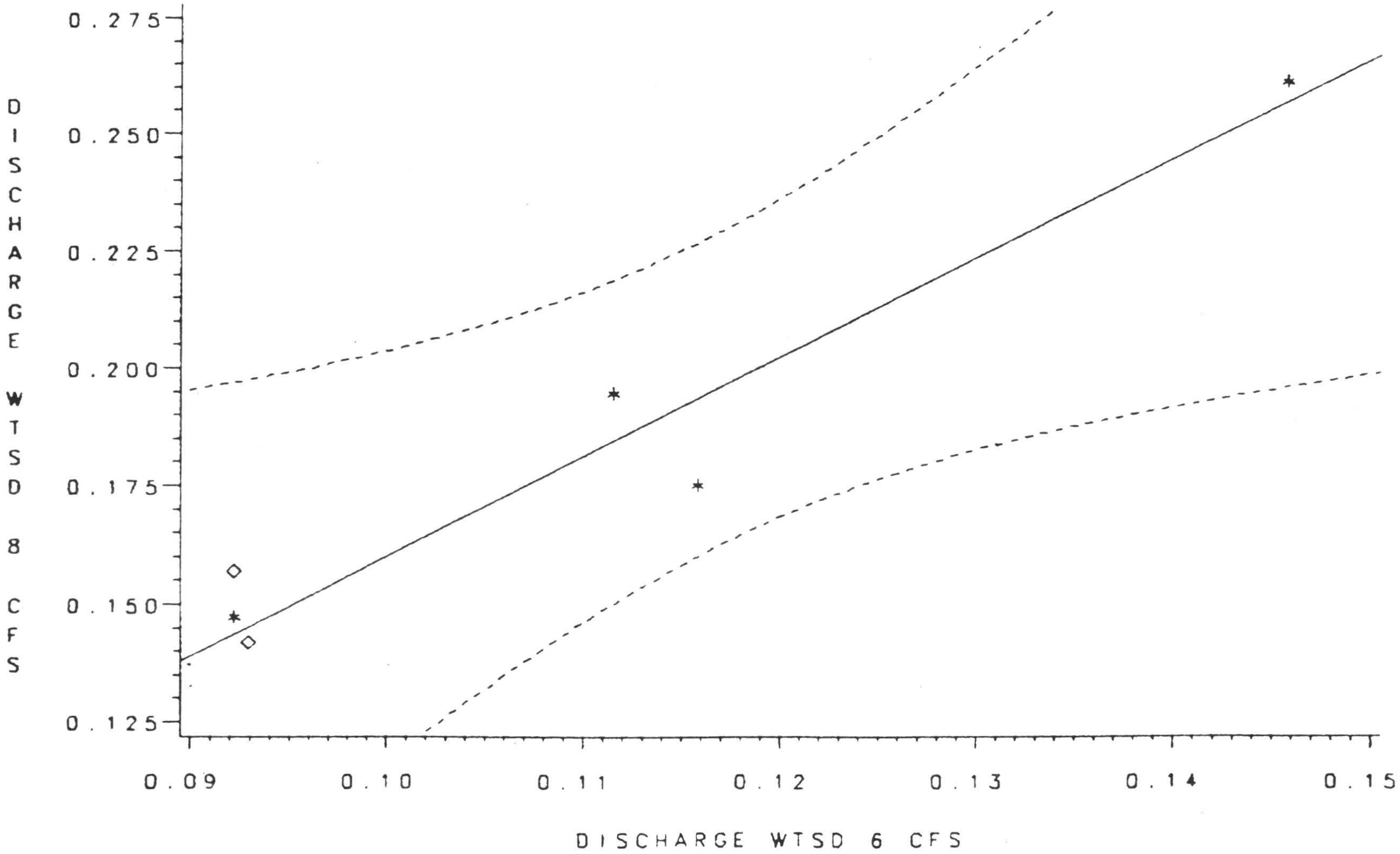


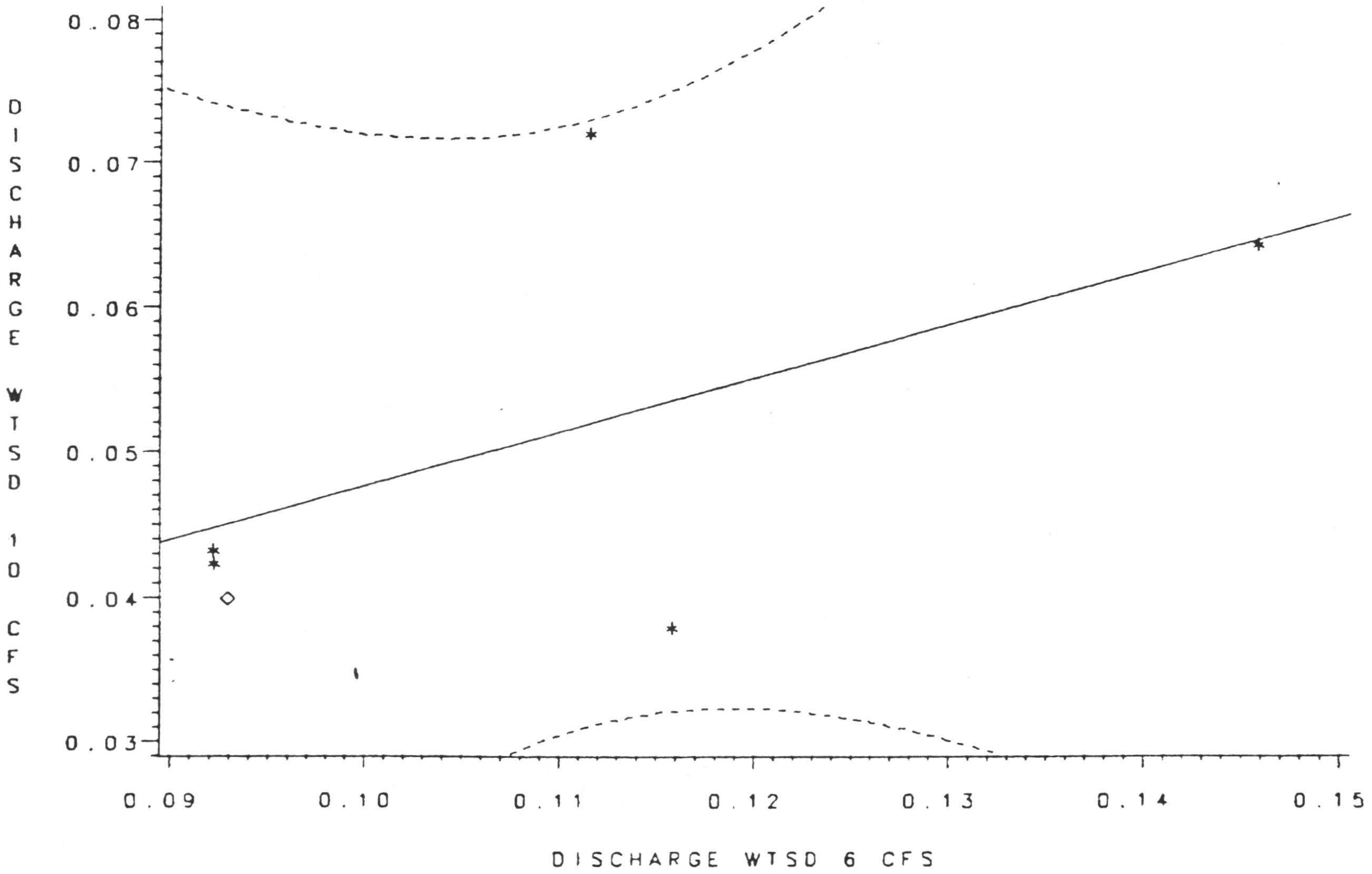
CALIBRATION--WATERSHED 8

MINIMUM STREAM DISCHARGE



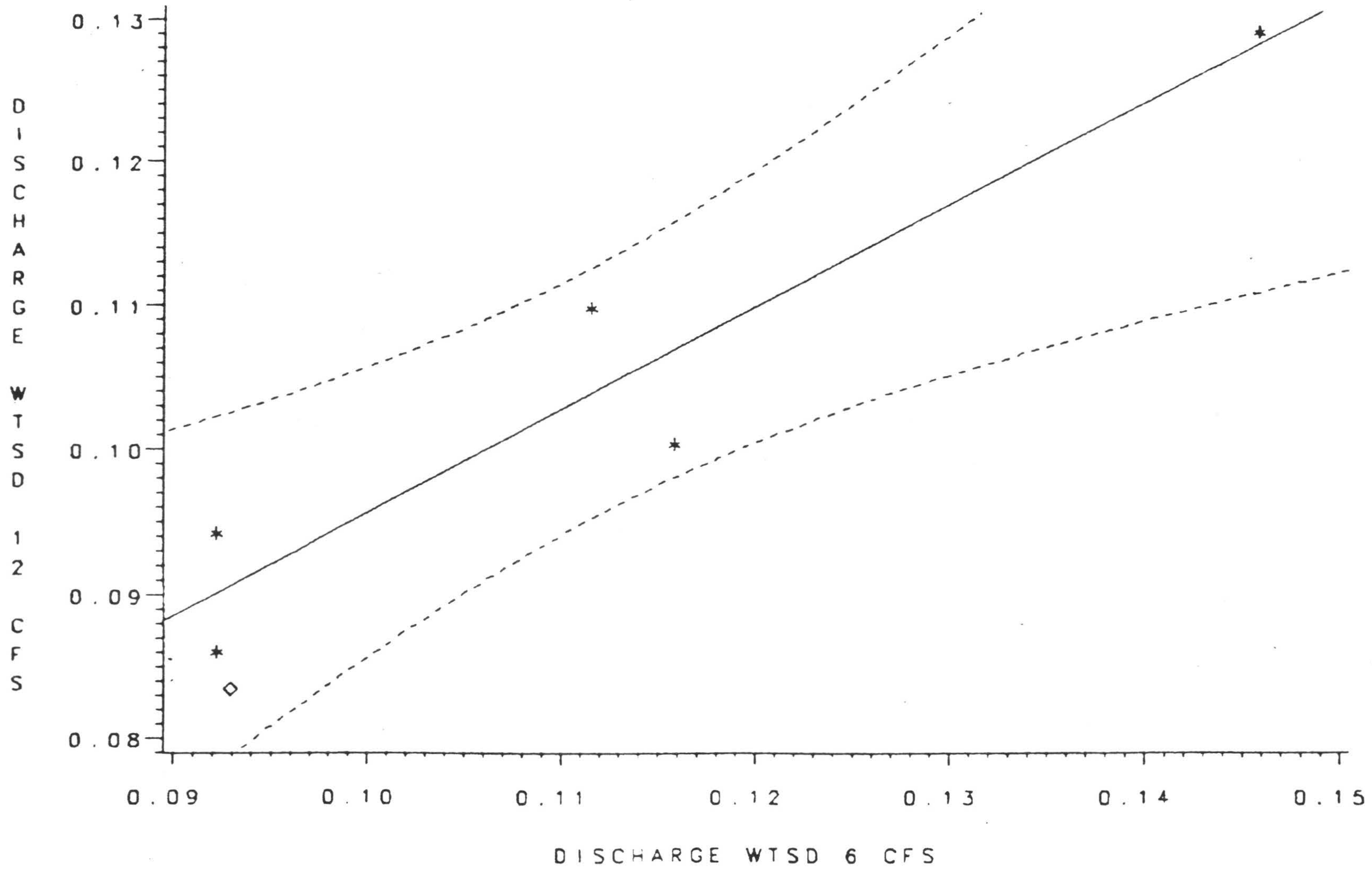
CALIBRATION--WATERSHED 10

MINIMUM STREAM DISCHARGE



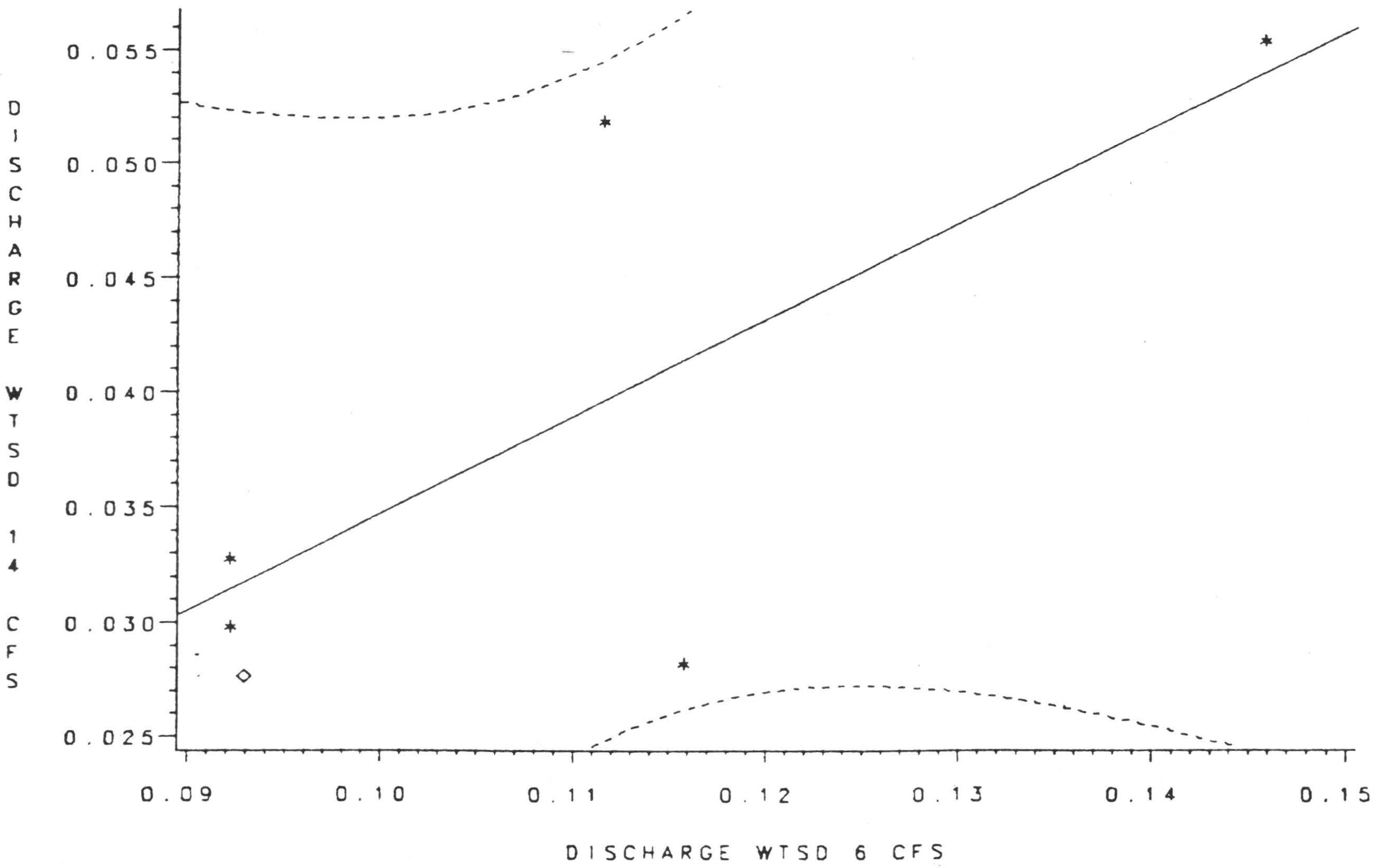
CALIBRATION--WATERSHED 12

MINIMUM STREAM DISCHARGE



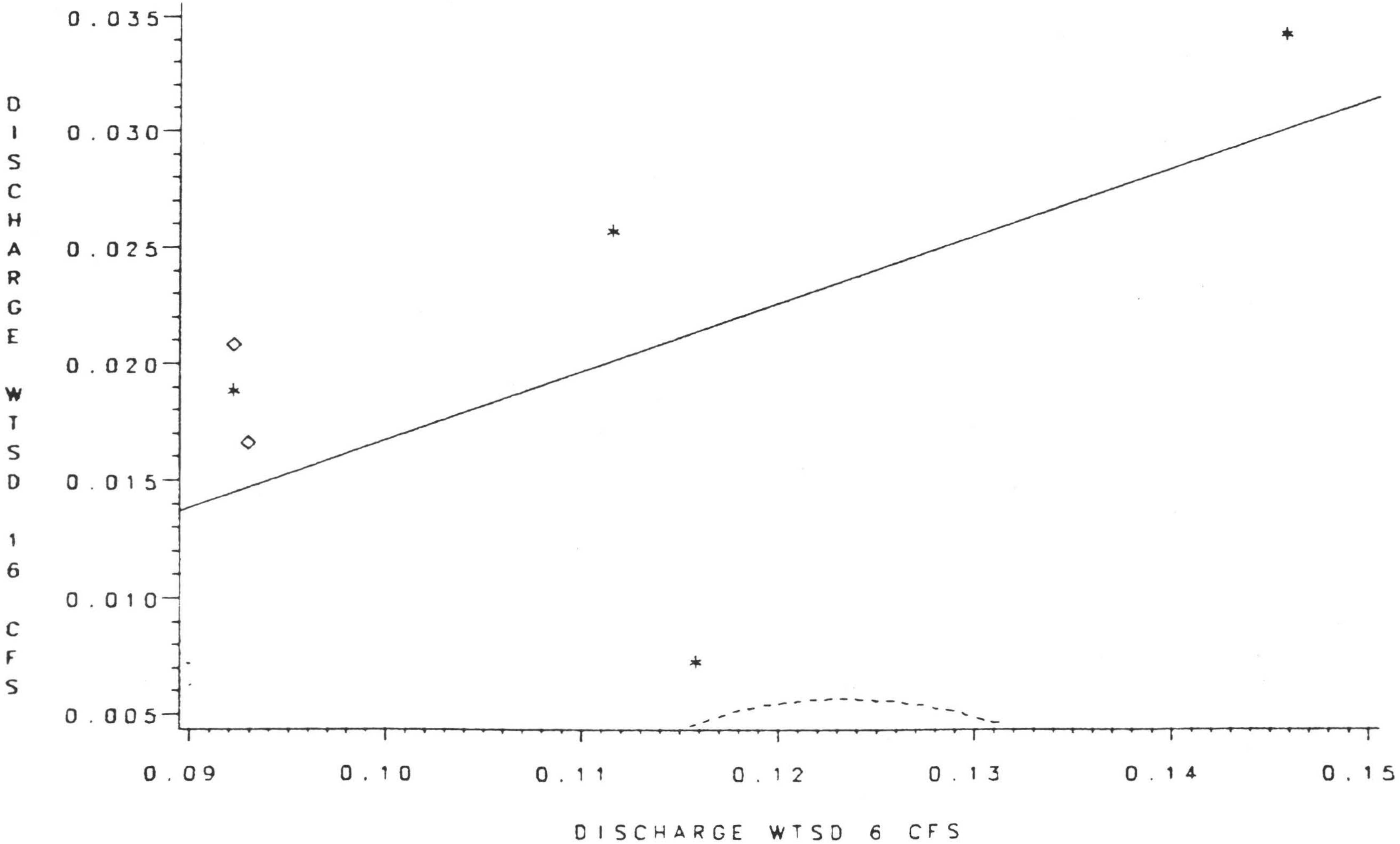
CALIBRATION--WATERSHED 14

MINIMUM STREAM DISCHARGE



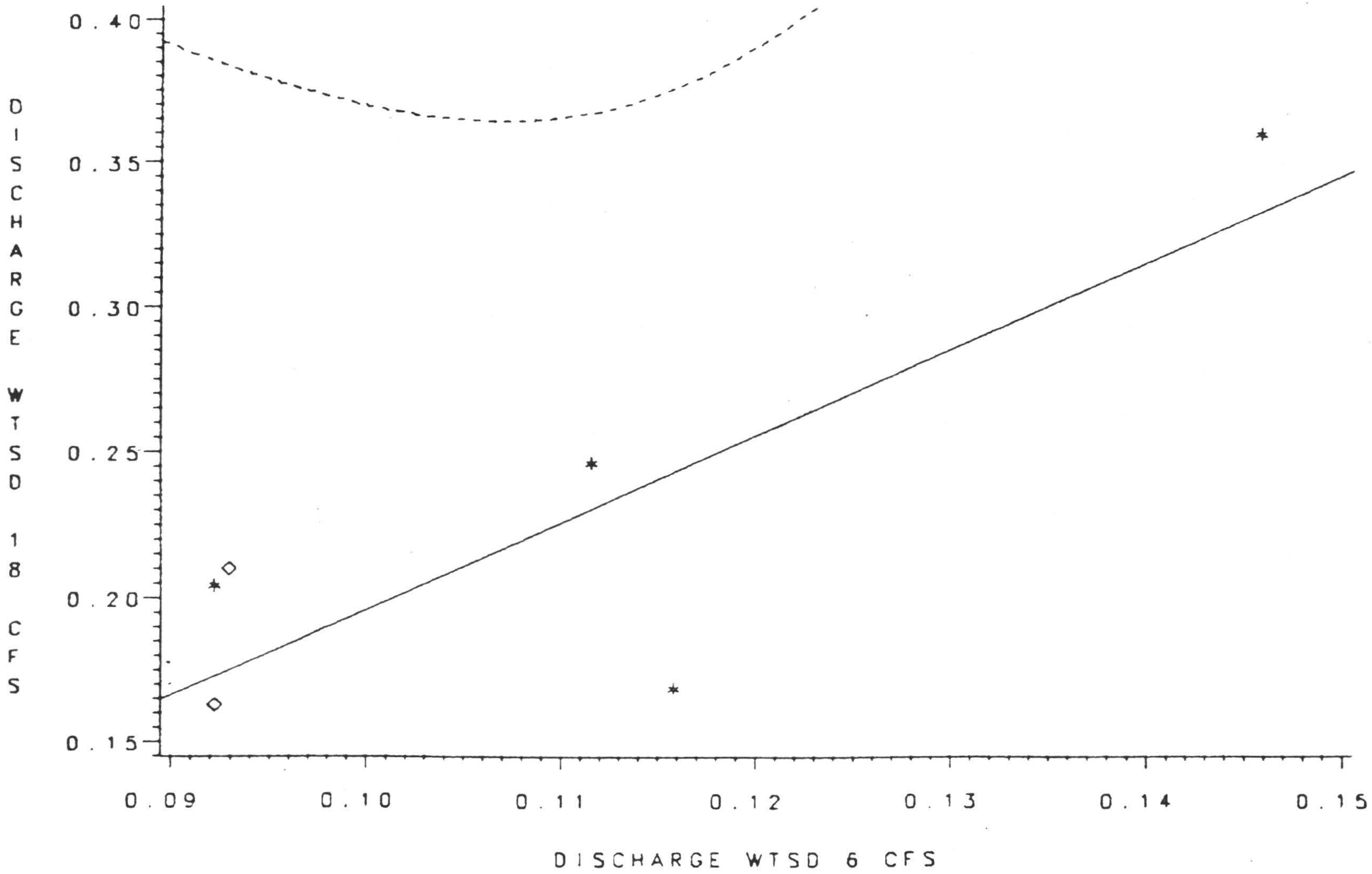
CALIBRATION--WATERSHED 16

MINIMUM STREAM DISCHARGE



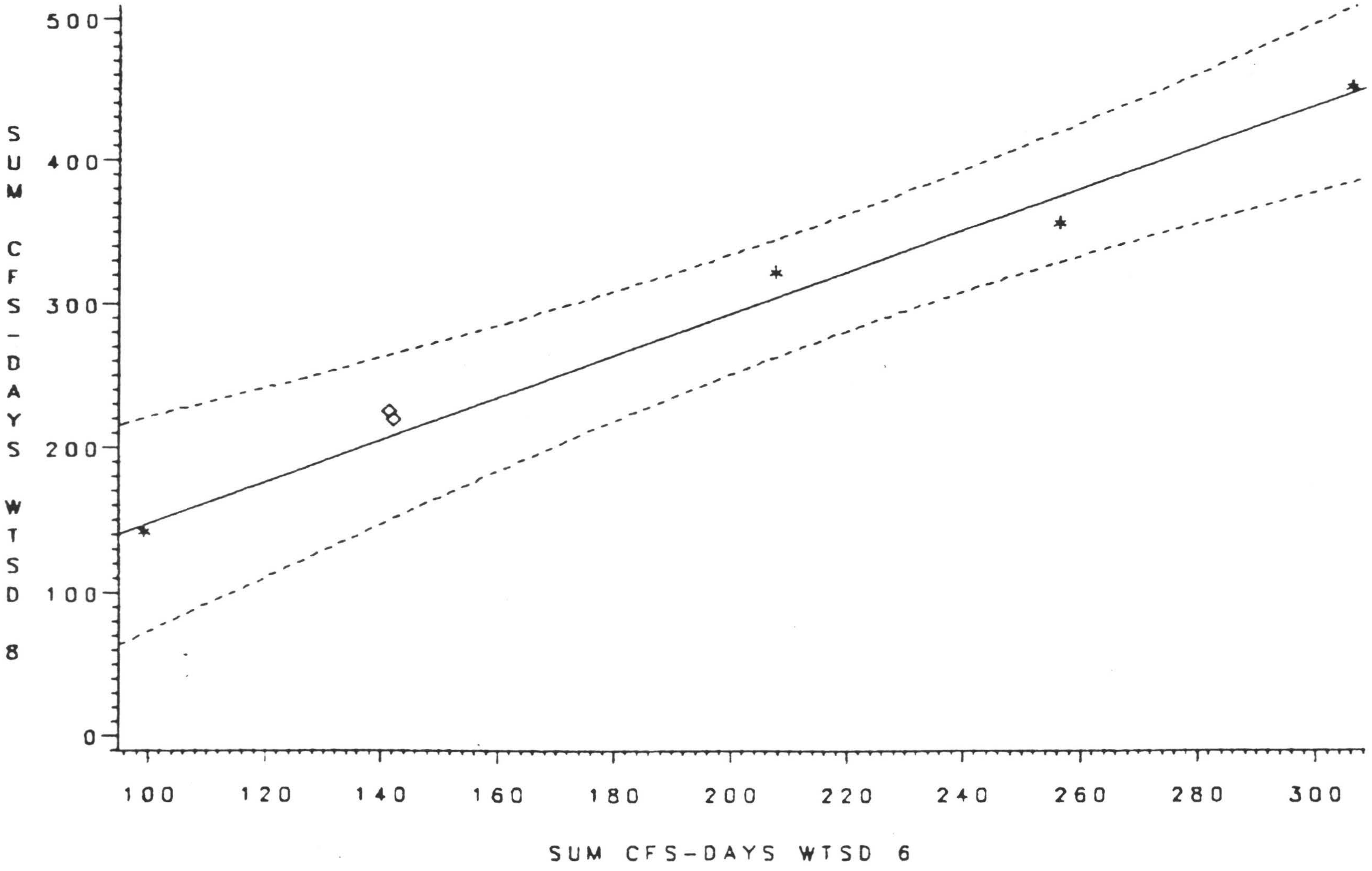
CALIBRATION--WATERSHED 18

MINIMUM STREAM DISCHARGE



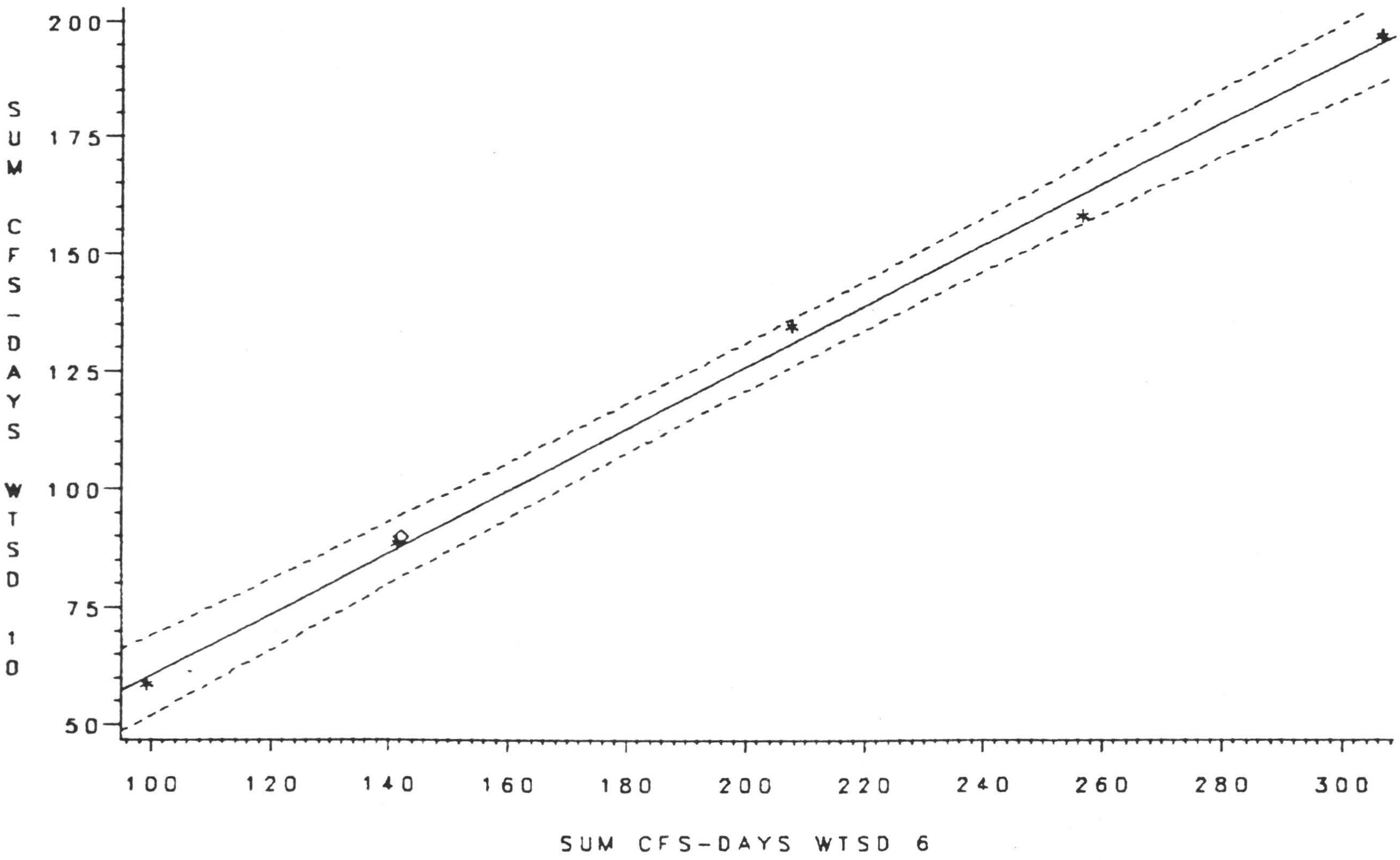
CALIBRATION--WATERSHED 8

TOTAL ANNUAL RUNOFF



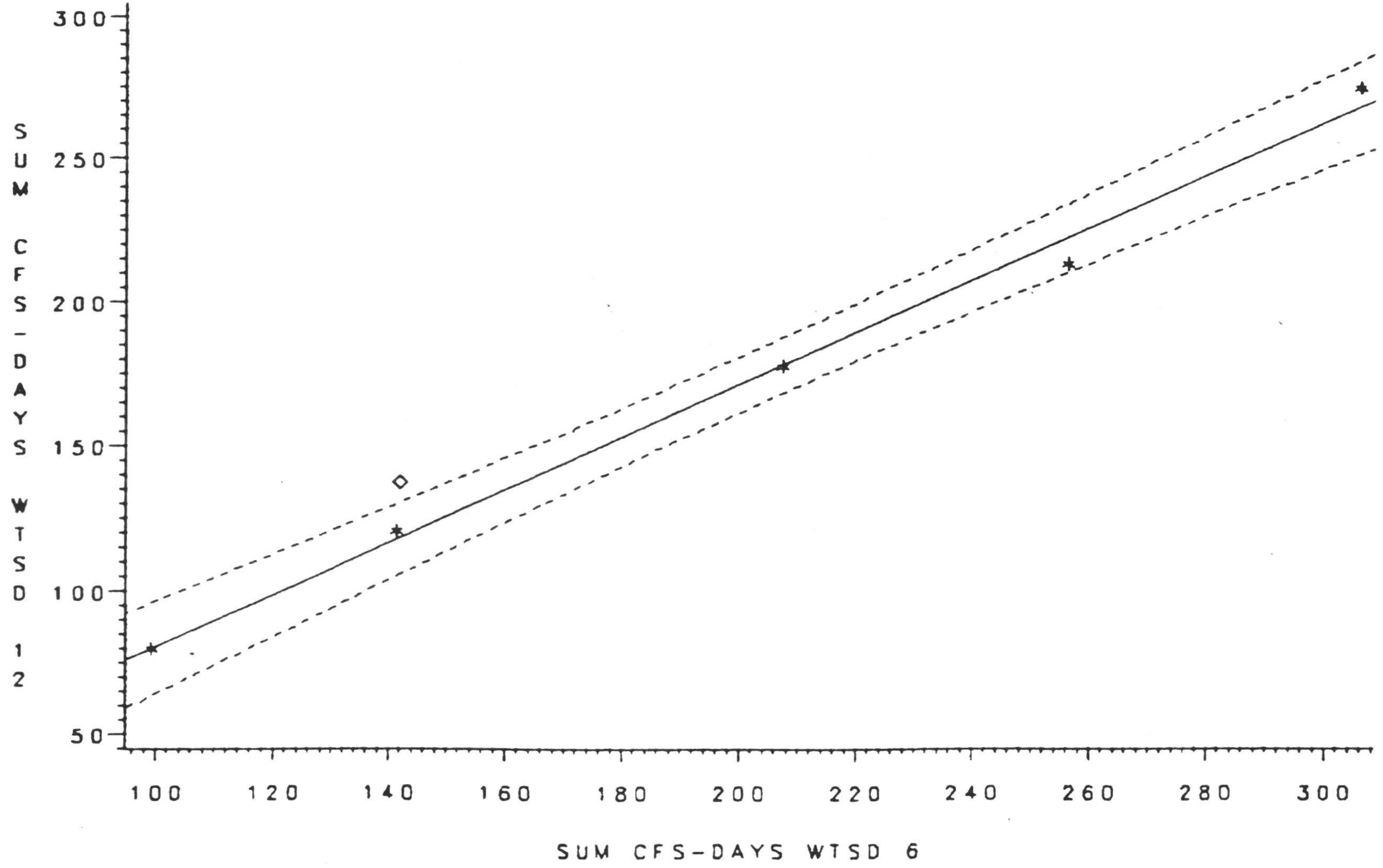
CALIBRATION--WATERSHED 10

TOTAL ANNUAL RUNOFF



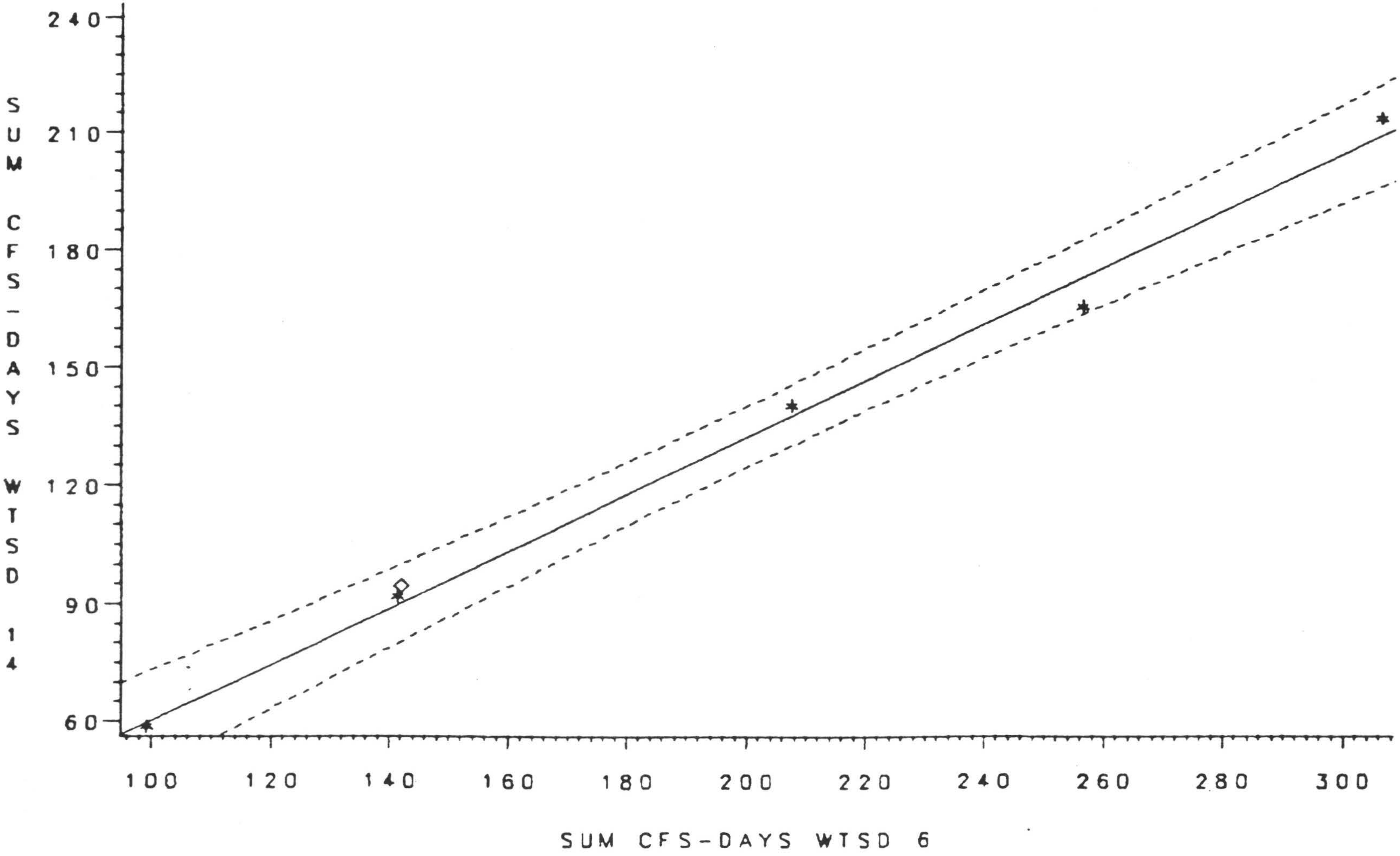
CALIBRATION--WATERSHED 12

TOTAL ANNUAL RUNOFF



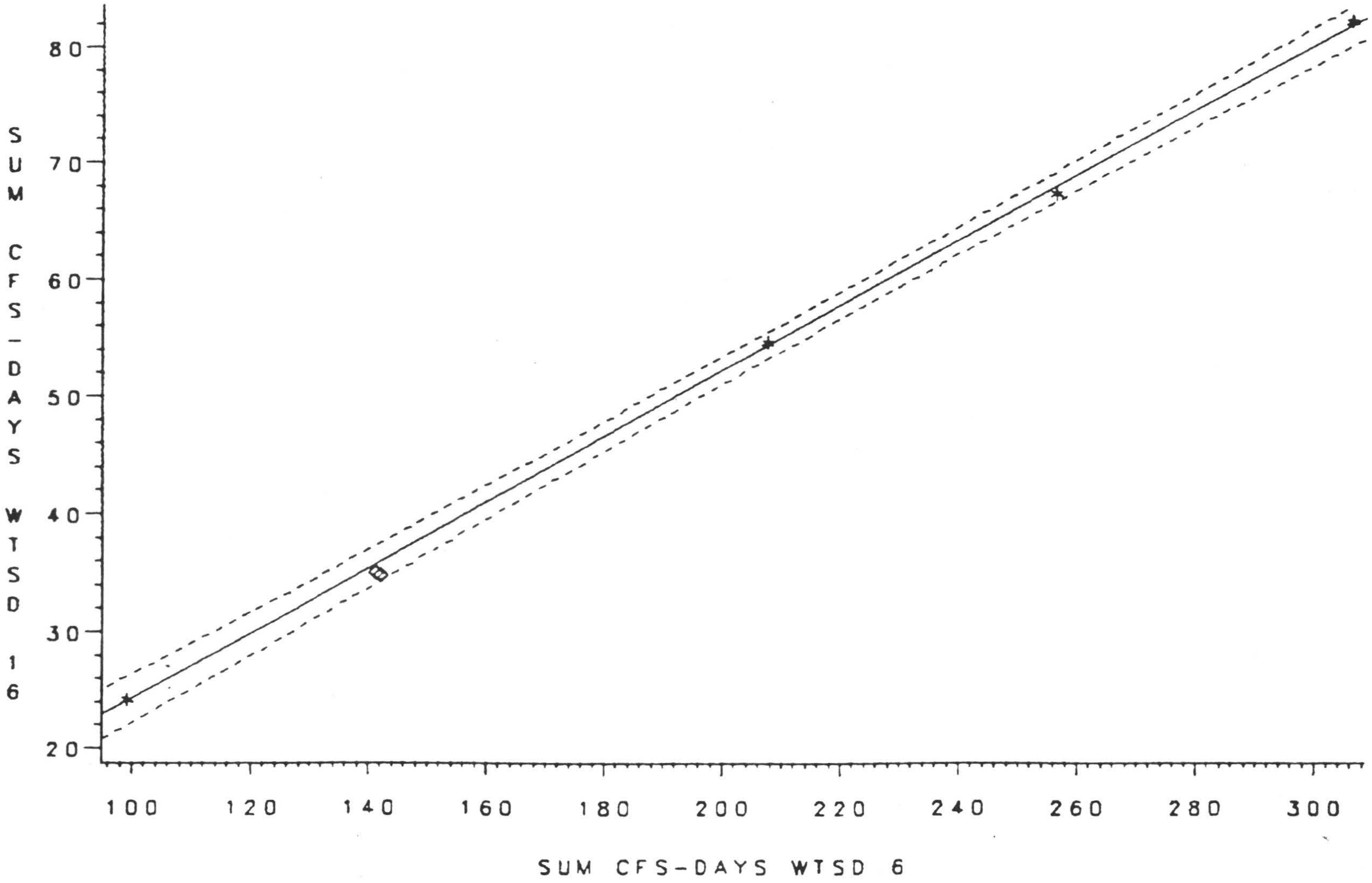
CALIBRATION--WATERSHED 14

TOTAL ANNUAL RUNOFF



CALIBRATION--WATERSHED 16

TOTAL ANNUAL RUNOFF



CALIBRATION--WATERSHED 18

TOTAL ANNUAL RUNOFF